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Phase 1 Program Joint Report

George C. Nield and Pavel Mikhailovich Vorobiev, Editors

January 1999

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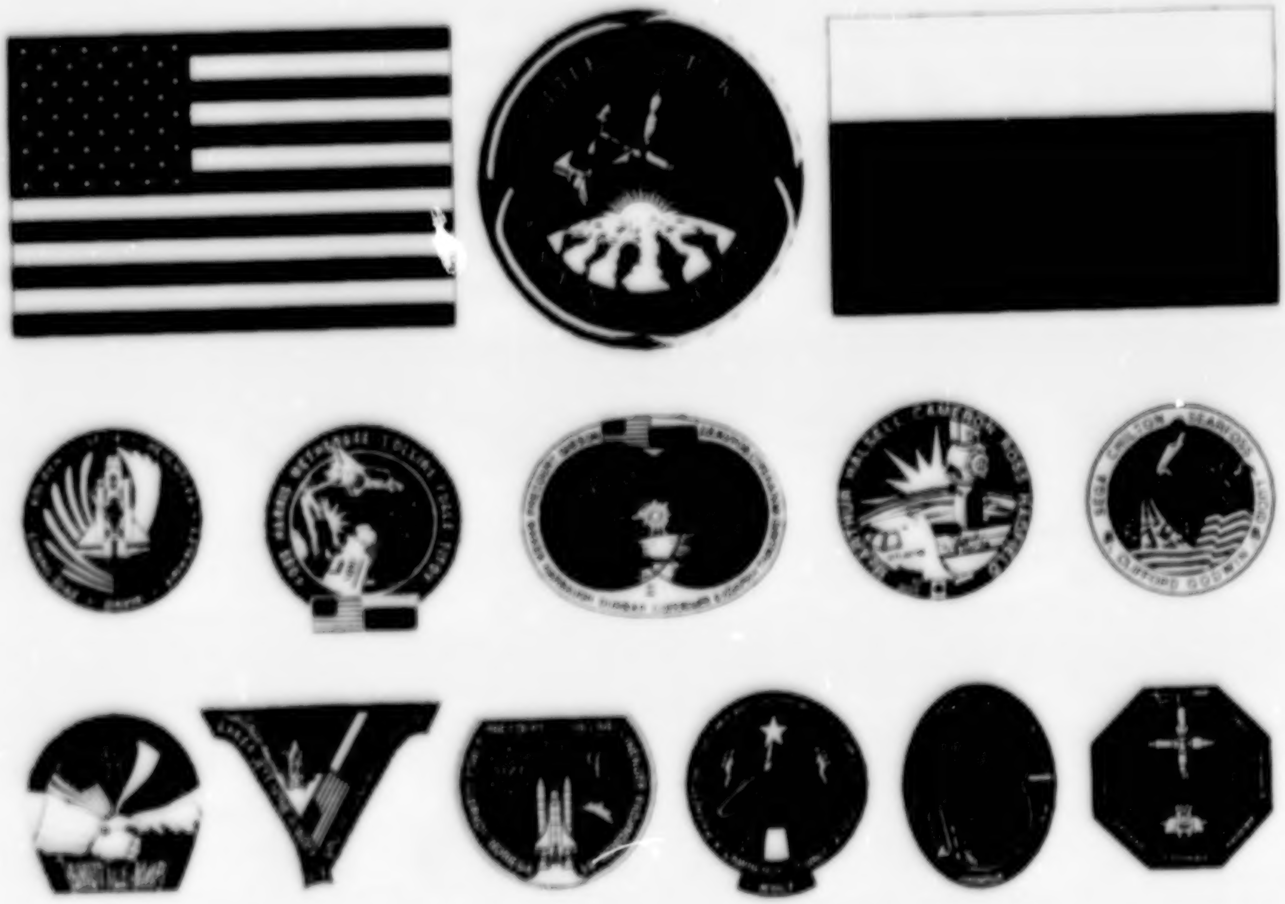
Phase 1 Program Joint Report

George C. Nield *and* *Pavel Mikhailovich Vorobiev*
Chief U. S. Editor *Chief Russian Editor*

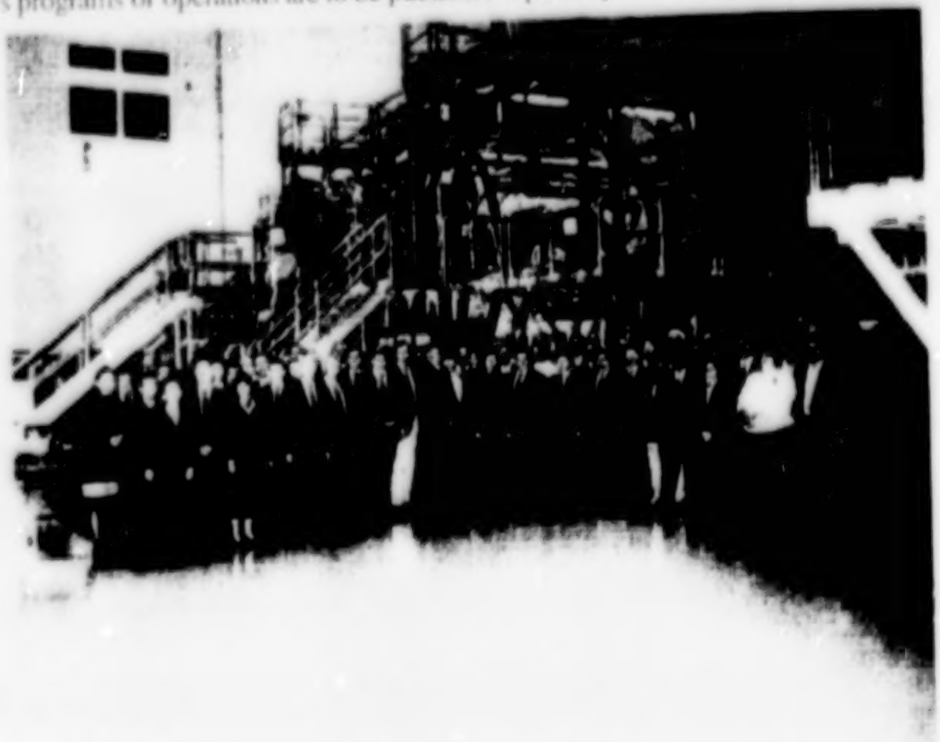


January 1999

PREFACE

This report consists of inputs from each of the Phase 1 Program Joint Working Groups. Most of the material was written and agreed to during a Team 0 Management Working Group Meeting at the NASA Johnson Space Center, July 13-16, 1998. For this report, the Working Groups were tasked to describe the organizational structure and work processes that they used during the program, joint accomplishments, lessons learned, and applications to the International Space Station Program. The primary authors for each section are listed at the beginning of the section, along with a list of the members of the related Working Group. At the conclusion of the meeting, the Russian and American Working Group Chairmen, or their designated representatives, approved the technical content of their sections. Editing of the report has primarily been limited to formatting and layout changes. Although having multiple authors resulted in some overlap and style differences between the sections, it offered the significant advantage that each subject area write up was prepared and approved by the appropriate technical experts.

The report is intended to be a top-level joint reference document that contains information of interest to both countries. Detailed scientific and technical results, crew consensus reports, and material that only apply to a single country's programs or operations are to be published separately.



Participants in the Team 0 Management Working Group meetings held prior to launch of STS-89

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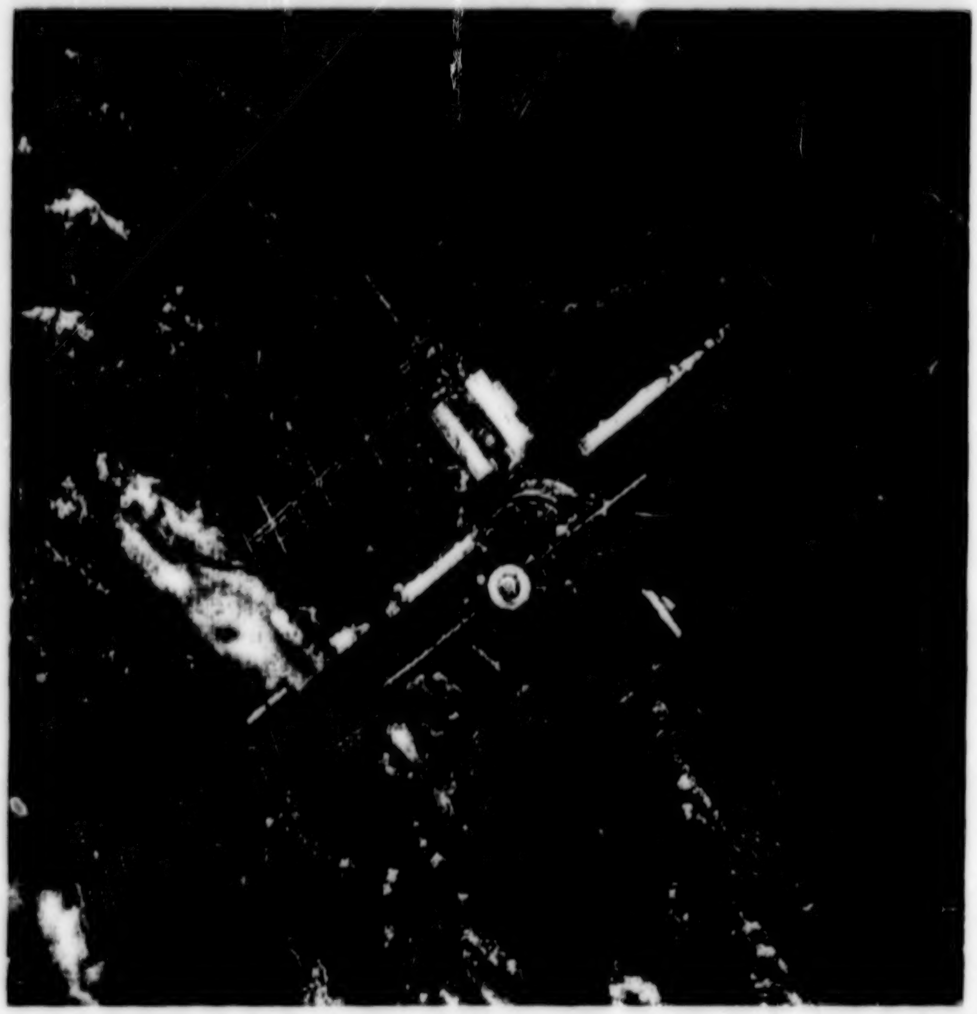

The *Mir* Space Station as seen by the Shuttle *Atlantis* during STS-86

The launch of Shuttle *Atlantis* for STS-71

Section 1 - Introduction

Authors:

Pavel Mikhailovich Vorobiev, Co-Chair of the Cargo and Scheduling Subgroup

Lynda Gavin, Technical Assistant to the Phase 1 Program Manager

1. The largest benefit of the Phase 1 Program was the growth of trust and understanding between National Aeronautics and Space Administration (NASA) and the Russian Space Agency (RSA). The Phase 1 Program underwent many changes from the original program plan, including many significant contingencies and several emergencies. At the end of the program the ability of the management and Working Groups to work together and support each other through all of the challenges improved to a level that was inconceivable during the "Cold War" or even just 6 years earlier at the start of the Phase 1 program. This report contains a brief description of *Mir*-Shuttle and *Mir*-NASA program operations, the main achievements of the programs, and also lessons and recommendations for International Space Station (ISS) operations.

1.1. How the Phase 1 Program Started

On June 17, 1992 in Washington D.C., George Bush, the President of the United States, and Boris Yeltsin, President of the Russian Federation, signed the "Agreement between the United States of America and the Russian Federation Concerning Cooperation in the Exploration and Use of Outer Space for Peaceful Purposes." This agreement states that one of the areas of cooperation will include a "Space Shuttle and *Mir* Space Station mission involving the participation of U.S. astronauts and Russian Cosmonauts." At this Washington meeting the leaders further agreed to flight(s) of Russian cosmonauts on the Shuttle in 1993, flight of a U.S. astronaut on a long-duration mission on *Mir* in 1994, and a docking mission between the Shuttle and the *Mir* in 1995. This was the beginning of the Phase 1 (*Mir*/Shuttle) Program.

On October 5, 1992, in Moscow, Daniel Goldin, Administrator of NASA, and Yuri Koptev, Director General of RSA, signed the "Implementing Agreement between the National Aeronautics and Space Administration of the United States of America and the Russian Space Agency of the Russian Federation on Human Space Flight Cooperation." This agreement further outlined details of cooperation that included: a Russian cosmonaut flying on the Shuttle mission STS-60 as a mission specialist; a U.S. astronaut launching on a Soyuz, flying more than 90 days on the *Mir*, and returning on a Shuttle; Russian cosmonauts on *Mir* being "changed out" via the Shuttle on the same flight that would return the U.S. astronaut; and evaluation of and possible contract for the Russian Androgynous Peripheral Docking Assembly developed by NPO Energia for use on the Shuttle. This program was called the *Mir*-Shuttle Program.

Later, the American side proposed expansion of the joint program: It would include up to 10 dockings of the Shuttle with *Mir* and would increase the presence of American astronauts on *Mir* to up to two years and deliver up to two tons of hardware on board the Russian Spektr and Priroda modules. Separate flights of up to six months were proposed for American astronauts on board *Mir*. In June 1994, a contract was concluded for work between RSA and NASA. This program was called *Mir*-NASA. The work performed for the *Mir*-Shuttle and *Mir*-NASA programs are considered as Phase 1 of the preparation for the creation of the International Space Station.

Initially Tommy Holloway at Johnson Space Center and Valeriy Ryumin at NPO-Energia were asked to be the technical program managers of the Phase 1 Programs on their respective sides of the Ocean. Working groups, consisting of experts from RSC Energia, NASA, RSA, Institute for Biomedical Problems (IBMP), Gagarin Cosmonaut Training Center (GCTC), and other organizations and companies, were created to prepare the organizational and technical documentation and to carry out the flight plans.

The Phase 1 Program became a formal stand-alone program on the NASA side on October 6, 1994 when Associate Administer for Spaceflight, Jeremiah Pearson III, signed a letter establishing the Program Plan and officially appointing Tommy Holloway as Manager. The Program Plan stated that:

"Pha[illegible]ents the building block to create the experience and technical expertise for [illegible]nternational Space Station. The program will bring together the United States and [illegible]sia in a major cooperative and contractual program that takes advantage of both count[illegible] capabilities."

In August of 1995, Frank Culbertson was named as the Phase 1 Program Manager, and he remained at this position for the duration of the Program.

1.2. Objectives and Working Group Structure

Phase 1 was a stepping stone to the ISS. It was a chance for NASA to learn from the Russians' experience of building and maintaining a Space Station, and for both counties' space programs to fit these experiences into the plans and implementation of the ISS.

The four main objectives of the Phase 1 Program were:

1. Learn how to work with international partners,
2. Reduce risks associated with developing and assembling a space station,
3. Gain operational experience for NASA on long-duration missions,
4. Conduct life science, microgravity, and environmental research programs.

To accomplish these objectives, a Joint Working Group Structure was developed. This structure divided the mission planning and execution tasks into 9 different functions. Each country designated a Co-Chair for each group who was responsible for that function. These Co-Chairs chaired joint meetings (usually weekly via telecon, and occasionally face to face) and were empowered to sign protocols that documented agreements that were made within their discipline. See Table 1.1 for a list of working groups, their area of responsibility, and the names of the Co-Chairs.

Phase 1 Joint Working Group (WG) Structure

Table 1.1

Working Group (WG) Number and Name	Area of Responsibility	Russian Chair (through most of the program)	NASA Chair (through most of the program)
WG-0 Management Working Group	Technical direction of all Phase 1 activities; coordination of activities of working groups	Technical Director (RSC-E) Valeriy Viktorovich Ryumin	Program Manager Frank L. Culbertson
	Technical coordination of RSA and NASA Activities	Technical Director (RSA) Boris Dmitryevich Ostroumov	Deputy Program Manager James E. Van Laak
	Established Configuration Management Control and standards for documents and communications	Deputy Technical Director (RSA) Aleksandr Grigoriyevich Botvinko	Contract Director James R. Nise
		Chairman of Crew Training (Gagarin Crew Training Center) Yuri Nikolayevich Glaskov	
	Coordination of Phase 1 Joint Milestone Template	Requirements Coordination (RSC-E) Anatoliy Vasilyevich Lomanov	Requirements Coordination Kathy Leary
WG-0 Cargo and Scheduling Subgroup	Joint manifesting, cargo traffic scheduling for *Mir*-NASA program, and cargo delivery to *Mir* by Shuttle	Co-Chair (RSC-E) Pavel Mikhailovich Vorobiev	Co-Chair Sharon Castle

Table 1.1 Cont.

Working Group (WG) Number and Name	**Area of Responsibility**	**Russian Chair (through most of the program)**	**NASA Chair (through most of the program)**
WG-1 Public Affairs Working Group	Plans, coordinates and implements all public affairs activities.	Co-Chair (MCC-M) Valeriy A. Udaloy	Co-Chair (Headquarters) Debra Rahn
WG-2 Joint Safety Assurance Working Group (JSAWG)	Evaluates safety requirements of the *Mir*/Shuttle Program, analyze off nominal situations, and review cargo safety	Co-Chair (RSC-E) Boris Ivanovich Sotnikov	Co-Chair Gary W. Johnson
WG-3 Flight Operations and Systems Integration Working Group	Develops flight programs, crew work schedules, and control, communications, and systems integration requirements. Performs analytical integration and operation analyses.	Co-Chair (RSC-E) Lead Mir Flight Director Vladimir Alekseyevich Solovyev Deputy Lead Mir Flight Director (RSC-E) Victor Dmitriyevich Blagov Deputy for *Mir* Integration (RSC-E) Yuri Pavlovich Antoshechkin	Shuttle Operations Co-Chair Philip L. Engelauf Shuttle Integration Co-Chair George Sandars
WG-4 Mission Science Working Group	Develops scientific programs and experiments, and requirements for scientific equipment.	Co-Chair (RSC-E) Oleg Nikolayevich Lebedev	Co-Chair John Uri
WG-5 Crew Training and Exchange Working Group	Develops requirements for crew functions, programs, schedules and crew training.	Co-Chair (RSC-E) Aleksandr Pavlovich Aleksandrov Co-Chair (GCTC) Yuri Petrovich Kargopolov	Co-Chair William C. Brown Crew Representative Shannon Lucid

Table 1.1 Cont.

Working Group (WG) Number and Name	Area of Responsibility	Russian Chair (through most of the program)	NASA Chair (through most of the program)
WG-6 Mir Operations and Integration Working Group	Coordinates the hardware integration, training, and operations activities of NASA hardware on Russian vehicles, for the *Mir* stand-alone operations (no Shuttle involved)	Co-Chair (RSC-E) Oleg Nikolayevich Lebedev	Co-Chair Rick Nygren
WG-7 Extravehicular Activity (EVA) Working Group	Defines the EVA requirements and the hardware required to support the EVAs.	Co-Chair Aleksandr Pavlovich Aleksandrov	Co-Chair Richard Fullerton
WG-8 Medical Operations Working Group	Defines requirements for health care systems in support of astronauts and cosmonauts involved in cooperative missions.	Co-Chair Valeri Vasilyevich Bogomolov (IBMP) Co-Chair (GCTC) Valeri Vasilyevich Morgun (GCTC)	Co-Chair Roger Billica Co-Chair Tom Marshburn

Astronaut Robert Gibson and cosmonaut Vladimir Dezhurov shake hands during STS-71

STS-60 cosmonaut, Sergei Krikalev

Section 2 - Program Description

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Anatoliy Lomanov, Requirements Coordination

Kathy Leary, Requirements Coordination

2.1. Description of the *Mir*-Shuttle and *Mir*-NASA Programs

The *Mir* Space Station program for 1994–98 was established by taking into account the following contents of the *Mir*-Shuttle and *Mir*-NASA programs:

2.1.1. Contents of the *Mir* Shuttle and *Mir*-NASA Programs

2.1.1.1. The *Mir*-Shuttle program included:

- Two independent flights (without docking with the *Mir* Space Station) of Russian cosmonauts on the Space Shuttle (STS-60 and STS-63).
- The flight of an American astronaut on the Soyuz-TM-21 vehicle (№ 70), his working on the *Mir* Space Station for three months, and his return on the Space Shuttle (STS-71)–NASA-1 increment.
- An American astronaut's operations on American science equipment that was delivered on the Spektr module.
- The flight of two Russian cosmonauts on the Space Shuttle (STS-71) in order to replace those flying on the *Mir* Space Station.
- The return from the *Mir* Space Station to Earth of two Russian cosmonauts on the Space Shuttle (STS-71).
- Execution of a short-term American mission on the *Mir* Space Station (STS-71).

2.1.1.2. The scope of the *Mir*-NASA program included the following:

- Eight dockings of the Space Shuttle with the *Mir* Space Station.
- Six long-duration missions of American astronauts on the *Mir* Space Station (with a period of residence on the *Mir* Space Station of 123 to 184 days and with an aggregate period of residence on the *Mir* Space Station of 831 days or 2.28 years).
- Eight short-term missions of American astronauts on the *Mir* Space Station (3 - 6 days).
- Development by the Russian side of a special docking module and the delivery thereof via the Space Shuttle to the *Mir* Space Station (STS-74) in order to preclude the movement of the Kristall module from the lateral assembly on the axial before every docking of the Space Shuttle.

- Delivery of American science equipment on the Spektr and Priroda modules.

- Installation of additional solar arrays on the Spektr module in order to provide for the power to be consumed by the American science equipment.

- Delivery by the Space Shuttle (STS-74) of two additional solar arrays for the Kvant module, one of which was furnished with American photoelectric converters.

- Operations on extending the service life of the *Mir* Space Station's onboard systems.

2.1.2. Basic Principles in Building the *Mir*-Shuttle and *Mir*-NASA Nominal Programs

When the *Mir* Space Station's nominal flight program was established for 1994–98, the following basic principles were taken into account:

2.1.2.1. All equipment and components of the life support system which are required for the flight of an American astronaut as per the *Mir*-Shuttle program (the astronaut for the first long-duration mission) shall be delivered to the *Mir* Space Station via Progress-M vehicles.

2.1.2.2. The American equipment that is to be initially installed on the *Mir* Space Station, and which supports the operations on the programs, shall be delivered on Spektr and Priroda modules and Progress vehicles.

2.1.2.3. As per the *Mir*-NASA program, the life support system's equipment and components shall be delivered by Space Shuttles in order to support the long-duration flight of American astronauts NASA 2-NASA 7.

2.1.2.4. According to the *Mir*-NASA program, the main Russian crews shall be rotated via Soyuz-TM vehicles.

2.1.2.5. The American astronauts shall be rotated via Space Shuttles.

2.1.2.6. Equipment and hardware intended to extend the *Mir* Space Station's service life and to maintain its viability, shall be delivered by Space Shuttles and Progress vehicles.

2.1.2.7. Worn-out American science equipment and hardware as well as Russian equipment and hardware shall be returned from the *Mir* Space Station by Space Shuttles.

2.1.2.8. Waste shall be removed from the *Mir* Space Station by Progress vehicles.

2.1.3. Measures That Support the Implementation of the Programs in the Event of Off-Nominal Situations

The *Mir* Space Station's flight program for 1994-98 provided for the following measures:

2.1.3.1. If there is a delay before the launch of a Space Shuttle, in order to ensure that one can recover from an off-nominal situation, provisions have been made for the necessary supply of consumable components for the *Mir* Space Station's onboard systems, propulsion systems and life support system supply to support flight for up to 40 days.

2.1.3.2. If there is a significant delay in launches of Soyuz-TM or Progress-M vehicles or Space Shuttles, or if there is docking failure with Spektr or Priroda modules, plans have been made for a reexamination of the *Mir*-Shuttle and *Mir*-NASA programs.

2.1.3.3. In the event that a launch is canceled or it is impossible for the Space Shuttle to dock (STS-71), the astronaut shall be returned to Earth together with the main crew on a Soyuz-TM vehicle. On subsequent flights, the astronaut can remain on board the *Mir* Space Station until the next docking with the Space Shuttle. Progress vehicles according to a separate contract shall provide life support system components for the American astronaut in this case.

2.1.3.4. If the Space Shuttle fails to dock within the scheduled time, a reserve of time has been provided to allow for an additional attempt at approach and docking. The docking time can be moved back by as much as two days.

2.1.3.5. If a Soyuz-TM vehicle fails to dock, termination of the manned flight program is possible.

2.1.3.6. An off-nominal situation on the Space Shuttle which could lead to loss of the vehicle's capability to return its crew from orbit to Earth or an off-nominal situation during which it would not be possible to separate the vehicle from the station is not deemed to be credible.

2.1.3.7. In the event that it is not possible to maintain the service life of a Soyuz-TM vehicle that is part of the *Mir* Space Station, the astronaut shall be returned to Earth on the Soyuz-TM together with the Russian crew.

2.1.3.8. With a view to using favorable flight conditions in mated configuration in order to increase the time for carrying out joint operations and counteracting off-nominal situations, one to two reserve flight days in the *Mir*-Shuttle mated configuration have been planned for in the flight program and provisions have been made for backup reserves of consumables.

2.1.3.9. If it is impossible to control the *Mir*-Shuttle mated configuration by the Space Shuttle, the *Mir* Space Station shall provide orientation for the mated configuration. When this happens, the duration of the joint flight may be reduced, depending upon the fuel supply on the station.

2.1.3.10. In order to counteract an off-nominal situation on board the *Mir* Space Station which results from the breakdown of equipment or hardware and which thereby places the station's functioning at risk, the capability exists to load a Space Shuttle in an emergency at the launch site within 40 hours before the launch with large-sized cargo having a mass of up to 120 kg.

2.1.4. Implementation of the *Mir*-Shuttle and *Mir*-NASA Programs

2.1.4.1. The implementation of the *Mir*-Shuttle program was carried out for two years from February 1994 through July 1995.

2.1.4.2. The implementation of the *Mir*-NASA program was carried out for three years from November 1995 through June 1998.

2.1.4.3. The specific time frames for vehicle flights and also the time frames for the Russian and American crew operations are given in the *Mir* Space Station's Flight Program (Section 2.2).

2.2. The *Mir* Space Station's Flight Program in 1994 - 98

The following designation has been adopted in the *Mir*/NASA Integrated Flight Schedules in Figure 2.1:

- The long rectangles show the residence in orbit of Soyuz-TM and Progress-M vehicles.
- The two-digit numbers in the rectangles show the numbers assigned to Soyuz-TM vehicles.
- The three-digit numbers in the rectangles show the numbers assigned to Progress-M vehicles.

- The two-digit numbers near the beginning and ending of the rectangles show the dates of launch and landing of Soyuz-TM vehicles respectively. For Progress-M vehicles, only the launch dates are given. The dates are given in Moscow time.

- The letter "E" in the circle shows extravehicular activity (EVA).

- The *Mir*-number shows the number of a Russian mission to the *Mir* Space Station, and the number in parentheses shows the period of residence of the mission's crew members on orbit in days.

- The NASA-number shows the number of the long-duration American mission to the *Mir* Space Station, and the number in parentheses shows the period of residence of the astronaut on orbit in days.

- CC means crew commander.

- FE means flight engineer.

- MS means mission specialist.

- The long lines show the residence of the crew members on orbit.

- The bold arrows pointing up or down show the launch or landing of Space Shuttles respectively. The numbers near the arrows show the dates of launch and landing according to Moscow time. The numbers in parentheses show the dates according to Houston time.

- The doubled diamonds show the docking and undocking of Space Shuttles. The numbers near the diamonds show the dates of docking and undocking respectively.

- The bold arrows pointing up, with the bold square on the side, show the launch and mating with the *Mir* Space Station of the Spektr and Priroda modules. The numbers near the arrows and the square show the dates of launch and mating of the modules respectively.

2.3. Phase 1 Joint Mission Information

Operation Schedules and Crew Members NASA 1 - NASA 7.

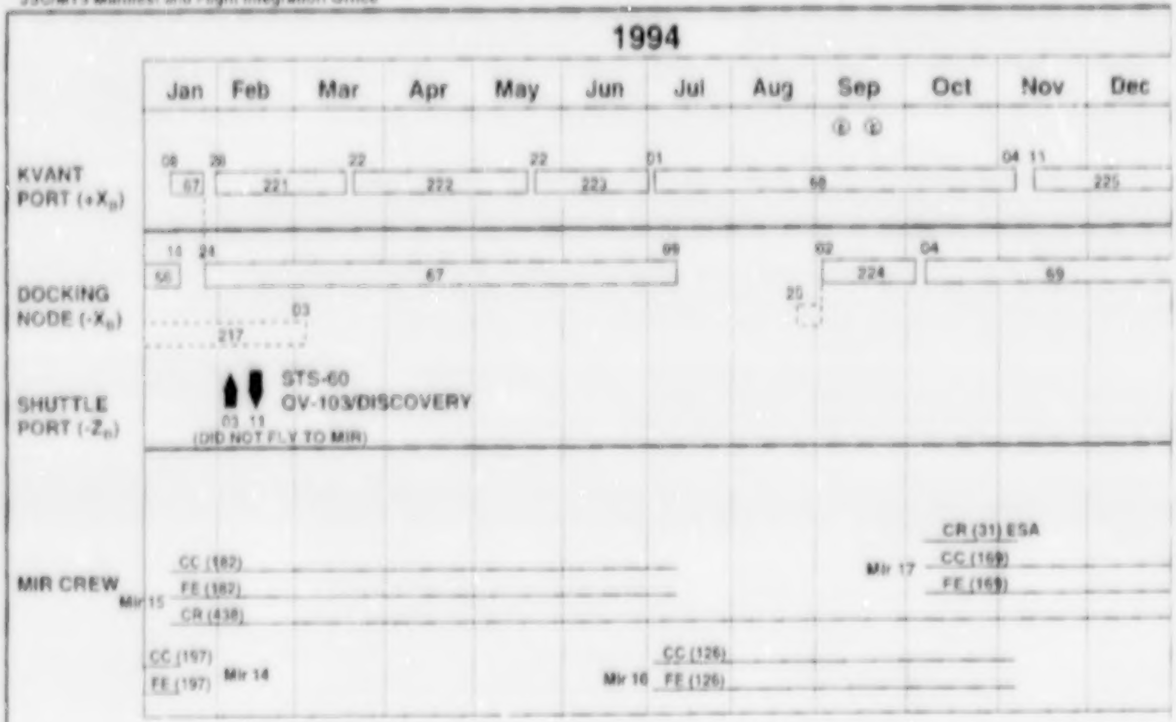
The dates and complement of U.S. long-duration missions on board *Mir* within the framework of *Mir*-Shuttle and *Mir*-NASA Programs as well as the dates of the U.S. crew's joint operations with the primary Russian expedition members are given in the Tables 2.2 and 2.3.

MIR/NASA INTEGRATED FLIGHT SCHEDULE

Figure 2.1

AUGUST 3, 1998

JSC/MT3 Manifest and Flight Integration Office



CC - Crew Commander
FE - Flight Engineer
CR - Cosmonaut Researcher

NASA - USA CREW
ESA - European Space Agency
Shuttle Docked with Mir xx◆-◆xx

Add two days after launch for Russian vehicle dock date
Ⓔ Extra Vehicular Activity (EVA)
(xx) Russian Date, Moscow Time

15

MIR/NASA INTEGRATED FLIGHT SCHEDULE

Figure 2.1 Cont.

AUGUST 3, 1998

JSC/MT3 Manifest and Flight Integration Office

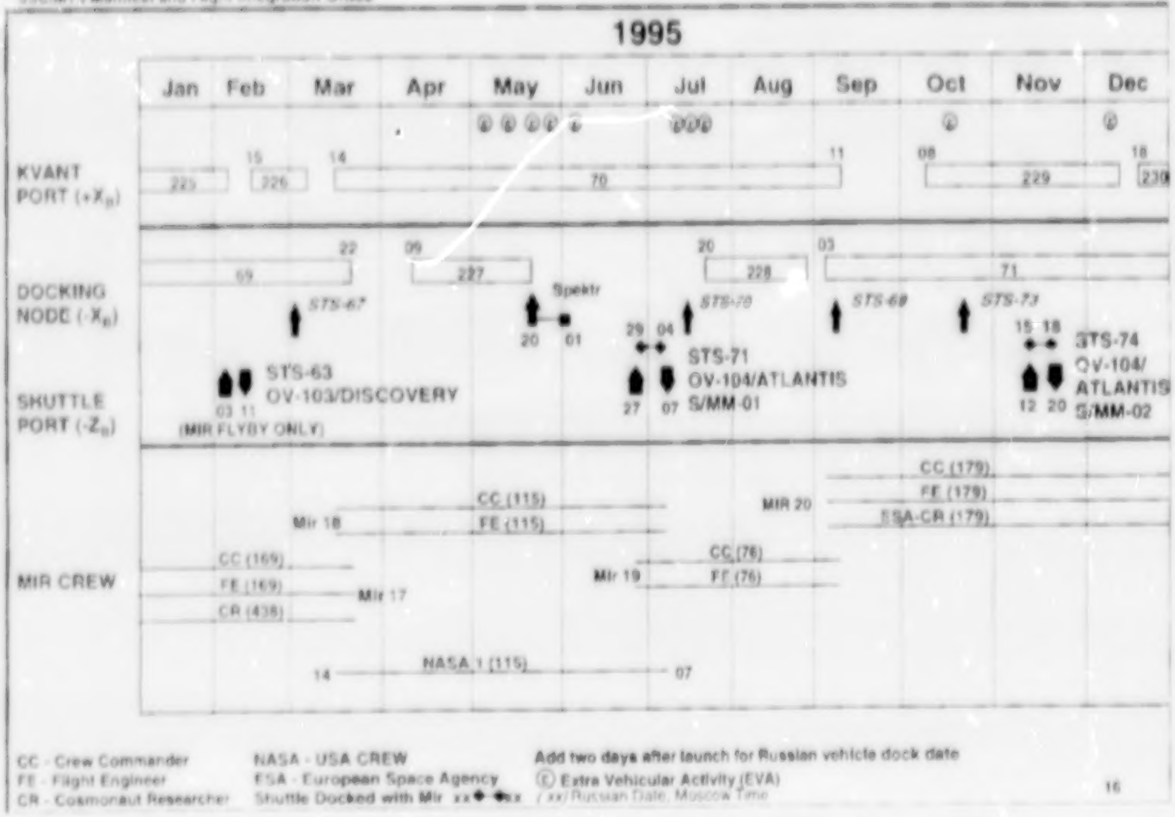
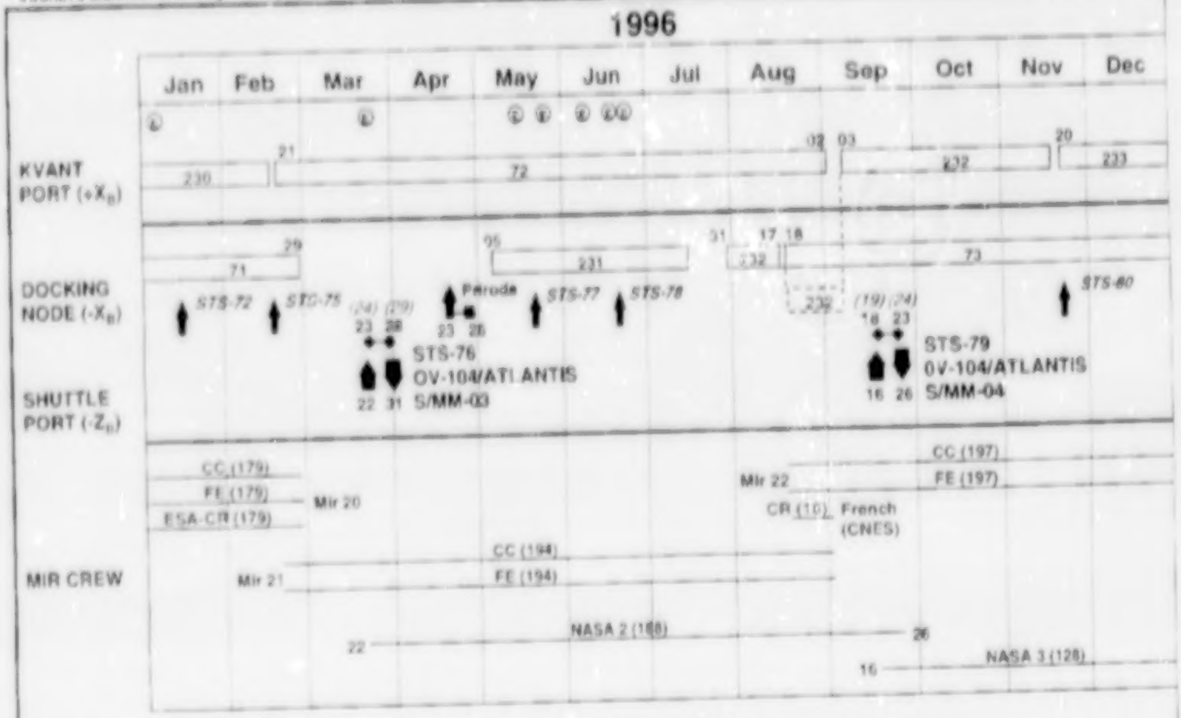


Figure 2.1 Cont.

MIR/NASA INTEGRATED FLIGHT SCHEDULE

AUGUST 3, 1998

JSC/MT3 Manifest and Flight Integration Office



CC - Crew Commander
FE - Flight Engineer
CR - Cosmonaut Researcher

NASA - USA CREW
ESA - European Space Agency
Shuttle Docked with Mir xx◆–◆xx

Add two days after launch for Russian vehicle dock date
Ⓔ Extra Vehicular Activity (EVA)
(xx) Russian Date, Moscow Time

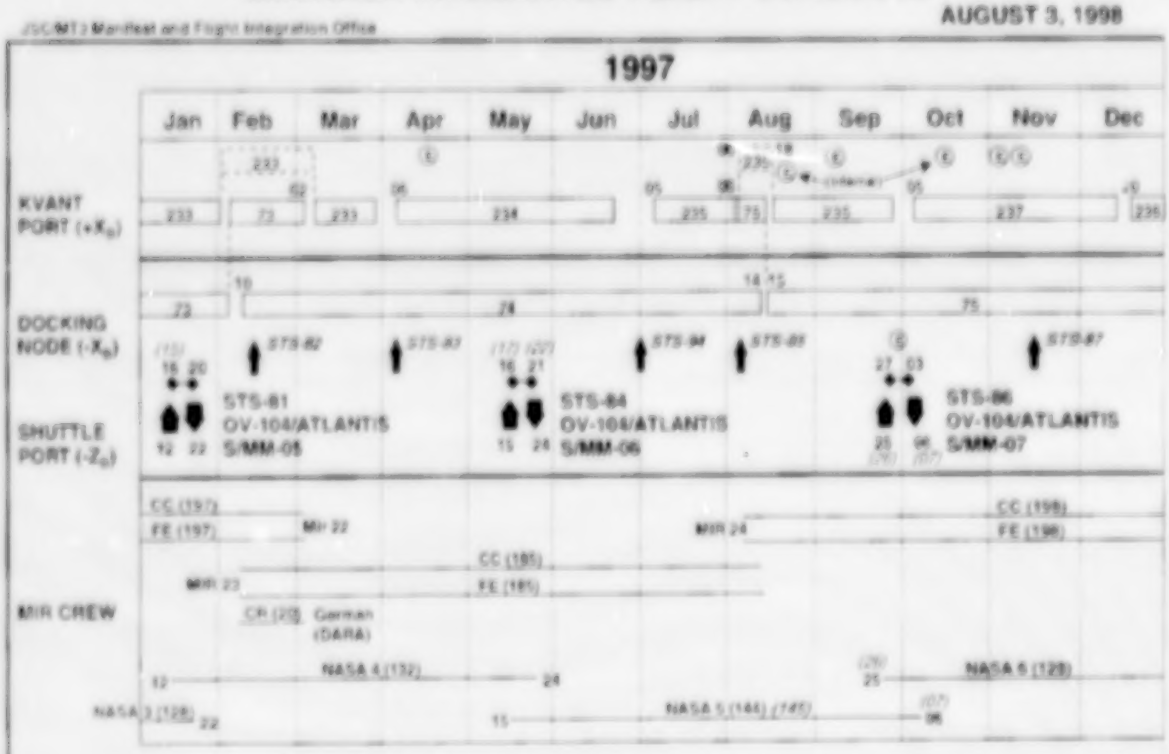
17

MIR/NASA INTEGRATED FLIGHT SCHEDULE

Figure 2.1 Cont.

AUGUST 3, 1998

JSC/MT3 Manifest and Flight Integration Office



CC - Crew Commander
FE - Flight Engineer
CR - Cosmonaut Researcher

NASA - USA CREW
ESA - European Space Agency
Shuttle Docked with Mir xx◆-◆xx

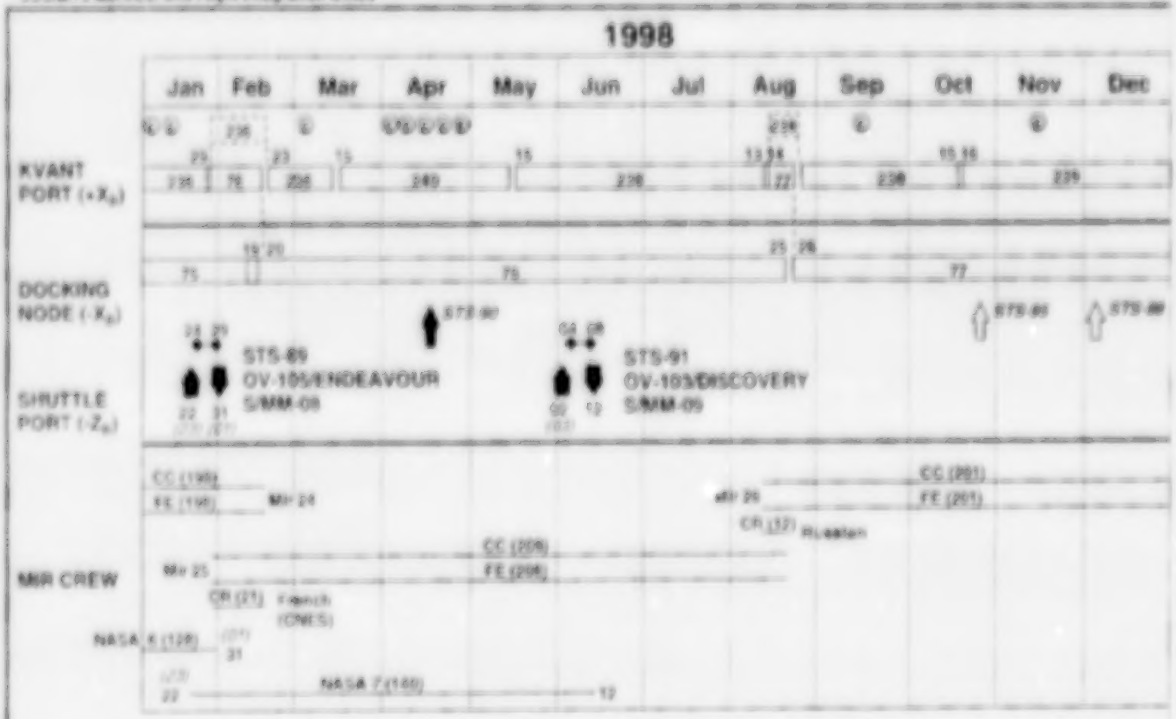
Add two days after launch for Russian vehicle dock date
Ⓔ Extra Vehicular Activity (EVA)
(xx) Russian Date, Moscow Time

MIR/NASA INTEGRATED FLIGHT SCHEDULE

Figure 2.1 Cont

JSC/MT3 Manifest and Flight Integration Office

AUGUST 3, 1998



CC - Crew Commander
FE - Flight Engineer
CR - Cosmonaut Researcher

NASA - USA CREW
ESA - European Space Agency
Shuttle Docked with Mir xx●-●xx

Add two days after launch for Russian vehicle dock date
Ⓔ Extra Vehicular Activity (EVA)
(xx) Russian Date, Moscow Time

Dates and complement of U.S. long-duration missions on board *Mir*

Table 2.2

NASA mission №., astronaut	**Delivery vehicle for *Mir*, launch date**	**Return vehicle, landing date**	**Days in orbit, Days on *Mir***	**Russian primary missions and crews**	**Dates of joint operations between the primary mission and NASA on *Mir***
NASA 1 Norman Thagard	Soyuz-70 03/14/95	STS-71 07/07/95	115 111	*Mir*-18 V.N. Dezhurov G.M. Strekalov	03/16/95- 07/04/95
NASA 2 Shannon Lucid	STS-76 03/22/96	STS-79 09/26/96	188 184	*Mir*-21 U.N. Onufrienko U.V. Usachev	03/24/96- 08/19/96
				Mir-22 V.G. Korzun A.Yu. Kaleri	08/19/96- 09/19/96
				CNES: Claudie Deshays	08/19/91- 09/02/91
NASA 3 John Blaha	STS-79 09/16/96	STS-81 01/22/97	128 123	*Mir*-22 V.G. Korzun A.Yu. Kaleri	09/19/96- 01/15/97
NASA 4 Jerry Linenger	STS-81 01/12/97	STS-84 05/24/97	132 127	*Mir*-22 V.G. Korzun A.Yu. Kaleri	01/15/97- 02/12/97
				Mir-23 V.V. Tsibliev A.I. Lazutkin	02/12/97- 05/17/97
				DARA: Rienhold Ewald	02/12/97- 03/02/97
NASA 5 Michael Foale	STS-84 05/15/97	STS-86 10/07/97	144 138	*Mir*-23 V.V. Tsibliev A.I. Lazutkin	05/17/97- 08/07/97
				Mir-24 A.Ya. Solovyev P.V. Vinogradov	08/07/97- 09/27/97
NASA 6 Dave Wolf	STS-86 09/26/97	STS-89 02/01/98	128 124	*Mir*-24 A.Ya. Solovyev P.V. Vinogradov	09/27/97- 01/24/98
NASA 7 Andrew Thomas	STS-89 01/23/98	STS-91 06/12/98	140 135	*Mir*-24 A.Ya. Solovyev P.V. Vinogradov	01/24/98- 01/31/98
				Mir-25 T.A. Musabaev N.M. Budarin	01/31/98- 06/08/98
				CNES: Leopold Eyherts	01/31/98- 02/19/98

$\sum$ = 975 days = 2.67 years (Astronaut time spent in orbit from time of launch to landing date)

$\sum$ = 831 days = 2.28 years (Astronaut time spent on *Mir*)

Dates and Complements of Phase 1 Missions

Table 2.3

MISSION	MISSION START EVENT	MISSION END EVENT	CREW	MISSION INFORMATION
STS-60	STS-60 Launch: 2/3/94	STS-60 Landing: 2/11/94	Cmdr: Charlie Bolden Pilot: Ken Reightler MS: Franklin Chang-Diaz MS: Jan Davis MS: Ron Sega MS: Sergei Krikalev	Krikalev is first cosmonaut on Shuttle
STS-63	STS-63 Launch: 2/3/95	STS-63 Landing: 2/11/95	Cmdr: Jim Wetherbee Pilot: Eileen Collins MS: Janice Voss MS: Bernard Harris MS: Mike Foale MS: Vladimir Titov	Rendezvous w/*Mir*, Cosmonaut Titov on Shuttle
Mir 18/NASA 1	Soyuz 70 Launch: 3/14/95	STS-71 Landing: 7/7/95	Cmdr: Vladimir Dezhurov Eng: Gennady Strekalov NASA 1: Norman Thagard	First U.S. Astronaut to launch on Russian Soyuz; First U.S. Astronaut on *Mir*
Spektr	Spektr Launch 5/20/95	N/A	Unmanned	Carries U.S. Research Hardware
STS-71	STS-71 Launch: 6/27/95	STS-71 Landing: 7/7/95	Cmdr: Robert "Hoot" Gibson Pilot: Charlie Precourt MS: Ellen Baker MS: Greg Harbaugh MS: Bonnie Dunbar MS: Norman Thagard Cosmonaut: Anatoly Solovyev Cosmonaut:: Nikolai Budarin Cosmonaut: Vladimir Dezhurov Cosmonaut: Gennadiy Strekalov	First Shuttle-*Mir* Docking; *Mir* 19 cosmonauts delivered to *Mir*; *Mir* 18 cosmonauts returned to earth; Spacelab Mission, Thagard, Dezhurov, Strekalov return to earth. Solovyev, Budarin remain on *Mir*.
Mir 19	STS-71 Launch: 6/27/95	Soyuz 70 Landing: 9/11/95	Cmdr: Anatoly Solovyev Eng: Nikolai Budarin	

Table 2.3 Cont.

MISSION	MISSION START EVENT	MISSION END EVENT	CREW	MISSION INFORMATION
STS-74	STS-74 Launch 11/12/95	STS-74 Landing: 11/20/95	Cmdr: Kenneth Cameron Pilot: James Halsell MS: Jerry Ross MS: William McArthur MS: Chris Hadfield	Second Shuttle-*Mir* Docking; Delivers Docking Module and Cooperative Solar Array
STS-76	STS-76 Launch: 3/22/96	STS-76 Landing: 3/31/96	Cmdr: Kevin Chilton Pilot: Richard Searfoss MS: Rich Clifford MS: Linda Godwin MS: Shannon Lucid MS: Ron Sega	Third Shuttle-*Mir* Docking; First EVA During Docked Operations; Lucid Delivered to *Mir*; First Spacehab Mission to *Mir*
NASA 2	STS-76 Launch: 3/22/96	STS-79 Landing: 9/26/96	NASA 2: Shannon Lucid	Stay lengthened approx 6 weeks due to launch slip
Priroda	Priroda Launch: 4/23/96	N/A	Unmanned	Carries 1000 kg U.S. research hardware
STS-79	STS-79 Launch: 9/16/96	STS-79 Landing: 9/26/96	Cmdr: Bill Readdy Pilot: Terrence Wilcutt MS: Tom Akers MS: Jay Apt MS: Carl Walz MS: John Blaha MS: Shannon Lucid	Blaha delivered to *Mir*; Lucid returned to Earth; First Double Spacehab Module

Table 2.3 Cont.

MISSION	MISSION START EVENT	MISSION END EVENT	CREW	MISSION INFORMATION
NASA 3	STS-79 Launch: 9/16/96	STS-81 Landing: 1/22/97	NASA 3: John Blaha	
STS-81	STS-81 Launch: 1/12/97	STS-81 Landing: 1/22/97	Cmdr: Mike Baker Pilot: Brent Jett MS: John Grunsfeld MS: Marsha Ivins MS: Peter "Jeff" Wisoff MS: Jerry Linenger MS: John Blaha	Linenger delivered to *Mir*; Blaha returned to Earth; Double Spacehab Module and SAREX II
				Linenger EVA in Russian Suit
NASA 4	STS-81 Launch: 1/12/97	STS-84 Landing: 5/25/97	NASA 4: Jerry Linenger	
STS-84	STS-84 Launch: 5/15/97	STS-84 Landing: 5/24/97	Cmdr: Charlie Precourt Pilot: Eileen Collins MS: Carlos Noriega MS: Edward Lu MS: Mike Foale MS: Jerry Linenger MS: Elena Kondakova ESA: Jean-Francois Clervoy	Foale delivered to *Mir*; Linenger returned to Earth; Cosmonaut (Kondakova) on Shuttle; Double Spacehab Module; SAREX II-21
				Foale EVA in Russian Suit
NASA 5	STS-84 Launch: 5/15/97	STS-86 Landing: 10/6/97	NASA 5: Mike Foale	
STS-86	STS-86 Launch: 9/25/97*	STS-86 Landing: 10/6/97*	Cmdr: James Wetherbee Pilot: Mike Bloomfield MS: Wendy Lawrence MS: Scott Parazynski MS: Mike Foale MS: David Wolf Cosmonaut: Vladimir Titov CNES: Jean Loup Chretien	Wolf delivered to *Mir*; Foale returned to Earth; U.S. EVA; Cosmonaut (Titov) on Shuttle; Double Spacehab Module
				Wolf EVA in Russian Suit
NASA 6	STS-86 Launch: 9/25/97	STS-89 Landing: 1/31/98	NASA 6: David Wolf	

Table 2.3 Cont.

MISSION	MISSION START EVENT	MISSION END EVENT	CREW	MISSION INFORMATION
STS-89	STS-89 Launch: 1/22/98*	STS-89 Landing: 1/31/98*	Cmdr: Terrence Wilcutt Pilot: Joe Frank Edwards, Jr. MS: Bonnie Dunbar MS: Michael Anderson MS: James Reilly MS: David Wolf MS: Andy Thomas Cosmonaut: Salizan Sharipov	Thomas delivered to *Mir*, Wolf Return to Earth Double Spacehab Module, OV-105
NASA 7	STS-89 Launch: 1/22/98	STS-91 Landing: 1/31/98	NASA 7: Andy Thomas	
STS-91	STS-91 Launch: 6/2/98*	STS-91 Landing: 6/12/98	Cmdr: Charlie Precourt Pilot: Dominic Pudwill Gorie MS: Wendy Lawrence MS: Franklin Chang-Diaz MS: Janet Kavandi MS: Andy Thomas Cosmonaut: Valeriy Ryumin	Thomas return to Earth; Single Spacehab Module, OV-103; Alpha Magnetic Spectrometer Payload

* Dates are Eastern Time (Kennedy Space Center Time)

2.3.1 Primary Mission Objectives of the *Mir*-Shuttle Program

2.3.1.1 Mission STS-60 (*Discovery*)

- Studying U.S. astronaut preflight training methods
- Flight operation training for the first Russian astronaut as a member of the Shuttle crew
- Carrying out the scientific experiments

2.3.1.2 Mission STS-63 (*Discovery*)

- Launching the Shuttle into orbit at an inclination of 51.6°
- Shuttle rendezvous with *Mir* (without docking)
- Checking voice communication between the Shuttle and *Mir* crews
- Coordinating operations of the Mission Control Centers
- Studying U.S. astronaut training methods
- Carrying out the scientific experiments

2.3.1.3 Mission Soyuz TM-21 (№ 70)

- Learning methods for training Russian cosmonauts
- Sending the first U.S. astronaut to *Mir* on the Russian vehicle Soyuz TM
- Flight operation training for the U.S. astronaut on the vehicle Soyuz TM and on *Mir* during a long mission
- Carrying out the joint scientific program

2.3.1.4 Spektr Scientific Module Mission and Deliveries as part of this module

- American scientific equipment for the *Mir*-Shuttle and *Mir*-NASA programs
- Russian scientific equipment
- Additional solar arrays

2.3.1.5 Mission STS-71 (*Atlantis*)

- Docking and undocking of the Shuttle with the *Mir* module Kristall, located on the axial node of the core module
- Exchanging the Russian *Mir*-18 and *Mir*-19 crews and returning the U.S. NASA 1 astronaut on the Shuttle
- Coordinating operations of Mission Control Centers
- Carrying out the scientific program
- Delivering Russian cargo
- Delivering technical water
- Returning experiment results, experimental equipment with an expired operational life, and orbital station equipment which has malfunctioned for analysis and reuse

2.3.2 Primary Mission Objectives of the *Mir*-NASA Program

2.3.2.1 Mission STS-74 (*Atlantis*)

- Docking the docking module on the Shuttle with the *Mir* Kristall module installed on the lateral node of the core module
- Delivering and mounting the docking compartment on *Mir* so that subsequent Shuttle dockings can occur without redocking of the Kristall module
- Delivering solar arrays to replace solar arrays on the Kvant module
- Delivering consumables and experimental equipment
- Returning the results of experiments, experimental equipment with an expired operational life, and orbital station equipment which has malfunctioned for analysis and reuse

2.3.2.2 Mission STS-76 (*Atlantis*)

- Docking the Shuttle to the docking module mounted on the Kristall module during flight STS-74
- Delivering astronaut NASA 2 to *Mir*
- Delivering consumables and experimental equipment, and returning the results of experiments
- Carrying the joint science program
- EVA— spacewalk of the American astronauts to mount the scientific equipment on the docking module (First U.S. astronaut EVA on the *Mir* surface)

2.3.2.3 Priroda Scientific Module Mission and Deliveries as part of this module

- U.S. scientific equipment for the *Mir*-NASA program
- Russian scientific equipment

2.3.2.4 Mission STS-79 (*Atlantis*)

- First U.S. astronaut handover between NASA 2 and 3
- Delivering consumables and replaceable equipment
- Emergency delivery of two vacuum valve units and a nitrogen purge unit
- Carrying the joint scientific program
- Returning the results of experiments and replaceable equipment with an expired operational life
- Dynamic testing of the *Mir*-Shuttle stack for *Mir*

2.3.2.5 Mission STS-81 (*Atlantis*)

- Crew exchange of NASA 3 and NASA 4
- Providing logistics, delivering life-support systems for the NASA and *Mir* crews, and scientific equipment
- Carrying out the joint scientific program
- Returning the results of experiments and replaceable equipment with an expired operational life and for reuse

2.3.2.6 Mission STS-84 (*Atlantis*)

- Crew exchange of NASA 4 and NASA 5
- Providing logistics, delivering life-support systems for the NASA and *Mir* crews, and scientific equipment
- Emergency delivery of Elektron system equipment
- Carrying out the joint scientific program
- Returning the results of the experiments, equipment with an expired operational life, and *Mir* equipment that has malfunctioned. (the mission which returned the most Russian cargo)

2.3.2.7 Mission STS-86 (*Atlantis*)

- Crew exchange of NASA 5 and NASA 6
- Providing logistics, delivering life-support systems for the NASA and *Mir* crews, and scientific equipment (the mission which delivered the most Russian cargo)
- Emergency delivery of equipment for repairing the Spektr module, the portable air pressurization unit and the Salyut-5 computer
- Carrying out the joint scientific program
- Returning the results of experiments, equipment with an expired operational life, and equipment for analysis and reuse
- EVA, first joint EVA performed from Shuttle: retrieving scientific equipment installed during Mission STS-76, and mounting the pressurization assembly on the docking module to repair the Spektr module

2.3.2.8 Mission STS-89 (*Endeavour*)

- Crew exchange of NASA 6 and NASA 7
- Providing logistics, delivering life-support systems for the crews and scientific equipment
- Emergency delivery of the air conditioning unit, compressor assembly, and the Salyut-5 computer to restore the *Mir* system

- Carrying out the joint scientific program
- Returning the results of experiments, equipment with an expired operational life, and *Mir* equipment that has malfunctioned

2.3.2.9 Mission STS-91 (*Discovery*)

- Returning astronaut NASA 7
- Providing logistics, delivering life-support systems for the *Mir* and scientific equipment
- Carrying out the joint scientific program
- Returning the results of experiments, equipment with an expired operational life, and *Mir* equipment that has malfunctioned

2.3.2.10 Transport-cargo Progress vehicle missions № 224, 226-238, 240

- Providing logistics and technical servicing of *Mir*, delivering life-support systems for the crew and scientific equipment
- Removing waste from *Mir*.

2.4 Shuttle Mission Preparation Joint Milestones

Joint Working Group activities to prepare for each Shuttle mission were jointly coordinated according to the "Joint Milestones" specified in WG-0/RSC-E/NASA/0002, as shown in Table 2.4. Beginning with the STS-81 mission, joint milestones were presented as diagrams with specific deadlines and responsible parties.

0002 JOINT MILESTONE TEMPLATE

LONG-DURATION MISSIONS

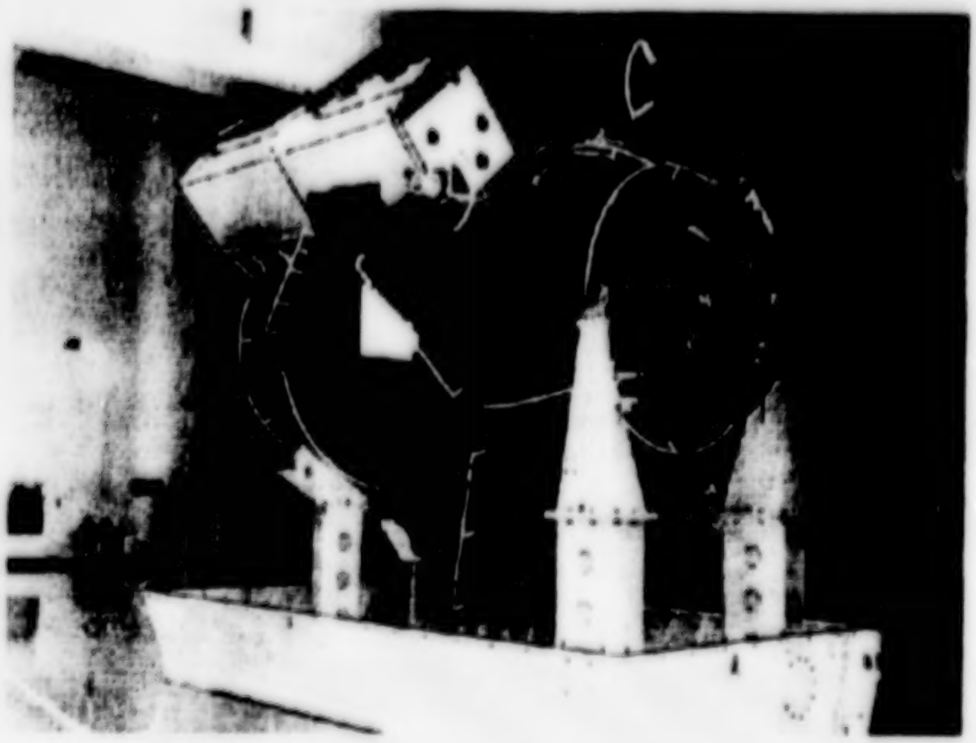
Table 2.4

Activity Owner	Template	Activity
1. Joint	L-12 Months	Define in 0002 Joint Mission operations and in-flight responsibilities of both sides /In English and Russian/.
2. US	L-11 Months	Draft DIDs for Non-Standard US H/W /In English/.
3. US (WG-6)	L-11 Months 7wks before US1 Trng	If necessary, deliver U.S. Experiment Procedures to RSC-E for new U.S. experiments (for US1 Training) /In English and Russian/.
4. Russia	L-10 Months 3 wks before US1 Trng	If necessary, deliver draft operating procedures to NASA for U.S. hardware /In Russian/.
5. Russia	L- 10 Months	Define in Document 0005 logistics that must be hard mounted (during ascent and return) /In English and Russian/.
6. Joint	L-9 Months	Start US1 Training.
7. US	L-9 Months	Deliver draft IPRD (Integrated Payload Requirements Document) to RSC-E and GCTC /In English and Russian/.
8. US	L-9 Months	Deliver Basic Configuration Information (DID) for Non-Standard U.S. equipment /In English/.
9. Joint	L-8 Months	Baseline SPACEHAB ICD for hard mounted logistics (In English and Russian).
10. US	L-8 Months	Delivery of training h/w to GCTC for crew training.
11. Joint	L-8 Months	Deliver Preliminary version of joint system integration documents (In English and Russian).
12. US	L-8 Months	Deliver 004 Baseline to RSC-E (Launch and Return Manifests)/In English/.
13. US	L-8 Months	Update Document 0005 with the preliminary list of all U.S. hardware listed in 004 /In English and Russian/.
14. Joint (WG-3)	L-7 Months	Baseline Preliminary version of joint flight operations (In English and Russian).
15. US (WG-6)	L-7 Months	Deliver 100 Series, EID, and Sketches /In English/.
16. Russia	L-7 Months	Beginning of Crew Training at GCTC.
17. Russia	L-7 to 6 Months	Define in 0005 Russian cargoes stowed in soft packages (In English and Russian).
18. US (WG-6)	L-6 Months	Deliver Preliminary (Basic) ORD /In English/.
19. US (WG-6)	L-6 Months	Deliver 004 Rev 1 (Launch, Return, On-Orbit Manifests)/In English/.
20. Russia	L-6 Months	Deliver ROP-2D Operations Document (Basic) (Preliminary Program, Service OPS timeline) /In Russian/.
21. Russia	L-6 Months	Define in 0007 Overall configuration of Nonstandard Experiment H/W /In English/.
22. US	L-6 Months (7 wks before US2 Trng)	Deliver U.S. Experiment Procedures for new U.S. Experiment to RSC-E (for US2 Training) /In English and Russian/.
23. Russia	L-6 Months	Preliminary Version of detailed EVA task and equipment list (Rev. 02) /In English and Russian/.
24. Joint	L-6 Months	Sign Preliminary 0005 list on transfer equipment (In English and Russian).
25. Russia	L-5 Months 3 wks prior to US2 Trng	RSC-E will deliver to NASA Onboard Instructions /In English/.
26. Russia	L-5 Months	Update of EVA procedures at GCTC /In English and Russian/.
27. US	L-4 wks before AT Approx. 5.5 Mos.	Deliver series 100 Documents to RSC-E (In English and Russian)
28. Russian	L-4 Months	Feasibility certificate for experiment program (In English and Russian).
29. US (WG-6)	L-4 Months	Deliver LDM Timeline input to RSC-E /In English/.
30. Joint (RSC-E/ WG-6)	L-4 Months	Start US2 Training.

Table 2.4 Cont.

Activity Owner	Template	Activity
31. US (WG-6)	L-3 Months	Deliver Final version of ORD (In English and Russian).
32. Joint	L-6 to L-3	Flight Hardware Acceptance Testing in U.S.
33. Joint	L - 3-4 Months	Baseline SPACEHAB ICD for Russian cargoes requiring only passive stowage and Attachment A (In English and Russian).
34. Joint	L-3 Months	Sign final version of Document 0005 for deliverable cargo to *Mir* (In English and Russian).
35. Russia	L-4-3 Months	Delivery by Russian side of hard mounted cargo.
36. US	L-3 Months	Deliver Final Redlines to Onboard Instructions (In English and Russian).
37. US	L-3 Months	Deliver Final 004 list of all scientific equipment (In English).
38. US	L-3 Months	Sign Final IPRD (Integrated Payload Requirements Document) (In English and Russian).
39. Joint	L-3 Months	Sign Final version of Joint Flight Operations Document (In English and Russian).
40. Joint	L-3 Months	Sign Final version of Detailed objectives of EVA description (Rev-02) (in English and Russian).
41. Russia	L-2.5 Months	Deliver by Russian side Soft Stowage Items.
42. Russian	L-2 Months	Define in document 0005 Russian Logistics: Final definition of Return Items in 0005 (In English and Russian).
43. Russian	L-2 Months	Delivery to U.S. side of safety certificates for Russian equipment to be transported on the shuttle (In Russian, category 2 certificates also in English)
44. US	L-2 Months	Delivery to Russian side of safety certificates for NASA equipment to be used on the *Mir* or transported on Russian cargo vehicles (In English, category 2 certificates also in Russian).
45. US (WG-6)	L-2 Months	Deliver Hazardous Materials Tables (In English).
46. US	L-2 Months	Deliver Final 004 (requires *Mir* Inventory at L-3 Months) (In English).
47. Russia	L-2 Months	Deliver ROP-2D (Final Timeline, Final Service Operations) (In Russian).
48. Russia	L-2 Months	Deliver Final Onboard Instructions (In Russian).
49. Joint	L-1.5-1 Months	All Joint Working Groups Sign certificates of flight readiness (in English and Russian).
50. Russia	L-1 Month	Delivery by Russian side of passively Stowage cargoes.
51. Russia	L-1 Month	Delivery to U.S. side of safety certificates for personal effects and packages for crew (cosmonauts) (In Russian, category 2 certificates also in English).
52. US	L-1 Month	Delivery to Russian side of safety certificates for personal effects and packages for crew (astronauts). /In English, category 2 certificates also in Russian/.
53. US	L-1 Month	Deliver Final version of all Spacehab ICDs, flight configuration mockup of Russian Cargoes (In English and Russian).
54. US	L-1 Month	Approval by NASA of Russian non-personal safety certs.
55. Russia	L-1 month	Approval by RSC-E of US non-personal safety certs.
56. US	L-2 Weeks	Delivery of DCNs for final changes to Document 0005 (in English and Russian).
57. Russia	L-2 Weeks	Approval by RSC-E of safety certificates for personal effects and packages for crew (astronauts).
58. Joint	L-2 Weeks	Incoming inspection of American equipment for *Mir* before installation on Shuttle.
59. US	L-2 Weeks	Approval by NASA of safety certificates for personal effects and packages for crew (astronauts) /In English and Russian/.
60. US	2 Weeks after flight	Handover to Russia side identified per document 0005 of urgently returnable cargoes as stated in Attachment A.
61. US	4 Weeks after flight	Handover to Russia side identified per document 0005 of remaining returnable cargoes.
62. Joint	1 month after flight	Issuance of joint summary report on transport of Russian cargoes.

Cosmonaut Valeriy Ryumin and astronaut Franklin Chang-Diaz during a training session



The docking module, which was attached to the *Mir* during STS-74

Section 3 - Shuttle Integration With *Mir*

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3.1 Introduction

This report presents a joint NASA-RSC Energia (RSC-E) summary of the significant activities and accomplishments of the Phase 1 Program Joint Systems Integration Working Group (SIWG). The managers of the Phase 1 Program (then known as the Shuttle-*Mir* Program) established the SIWG in November 1992. The SIWG was paired with the Flight Operations Working Group, to constitute Phase 1 Working Group 3 (WG-3) – Joint Flight Operations and Systems Integration. This report is divided into a number of stand-alone sections addressing the work and significant accomplishments in the various SIWG disciplines.

The Phase 1 Program SIWG was responsible for the physical interfaces and interactions between the Space Shuttle Orbiter and the *Mir* Orbital Station. NASA and RSC-E both have a long and successful legacy of human spacecraft design, development, and operations. Each organization had successfully performed complex engineering design and analysis tasks for many years on their respective spacecraft programs, addressing activities such as spacecraft rendezvous, docking, mated pressurized operations, and undocking. But the Phase 1 Program introduced new and unique engineering design and analysis challenges to both parties. Although the two organizations had previously cooperated in conducting the Apollo-Soyuz Test Project, the dramatic differences between the Apollo/Soyuz and the Shuttle/*Mir* spacecraft sets necessitated a fresh, comprehensive engineering assessment of all aspects of projected operations between the Shuttle and the *Mir*.

From the beginning of the systems integration joint work, the classical engineering project process was followed: requirements definition; design and analysis plan definition; data and information development and exchange; review of hardware designs and analysis results; and, finally, flight readiness recommendation and certification. Though the plan was simple, the work of integrating the efforts of two large, foreign engineering communities posed a number of administrative and technical challenges.

Developing a new, joint process for defining and documenting necessary engineering requirements was the first major step in our work. A series of 12 joint documents was eventually developed. Each document addressed a discrete engineering area, such as thermal control or structural mathematical models.

Many of the specific engineering tasks the parties performed were straightforward and similar, if not identical, to the standard tasks performed for Shuttle or *Mir* unilateral missions. But new and difficult spacecraft engineering issues were introduced to each party due to the complexities of the Shuttle and *Mir* spacecraft and the planned operations. The most challenging technical issues presented by the Phase 1 Program, requiring development of new analysis methodologies and/or new mathematical model development, were in the following areas:

- structural modeling and analysis
- docking dynamics
- rocket thruster plume impingement on large, flexible structures

- maneuvering and attitude control of large-scale mated vehicles
- habitable compartment atmosphere conditioning
- potable water treatment, transfer, and stowage
- Shuttle launch and orbital delivery/installation of a Russian space station module (*Mir* docking module, or DM)

A final area requiring joint development and agreement was formal certification for flight. Although each party had an existing flight certification process for their respective unilateral missions, these existing processes differed in a number of details. Therefore, the working group developed a plan whereby each party certified its individual spacecraft and equipment per their normal, unilateral flight certification processes, then signed a mutual statement that the two spacecraft were ready for the planned mission as defined in the joint engineering requirements.

Initially the Phase 1 program involved only one Shuttle-*Mir* docking mission. Within 18 months of inception however, the Program had expanded in scope to one rendezvous and 9 docking missions (all spaced approximately 4 months apart), including delivery of a Russian-built *Mir* DM for launch on the Shuttle and delivery to *Mir* on the second docking mission. Further, the relative docking/docked geometry of the Shuttle and *Mir* needed to be changed for the second docking mission (and then remained constant for the remaining missions) to accommodate periodic *Mir* resupply and expansion in parallel with routine Shuttle visits. This expansion of the Program scope significantly increased the scope and scale of work this working group had to accomplish before the first docking mission. The time and effort required to complete necessary bilingual documentation for these two very different mission scenarios imposed a large burden on the individual specialists over and above their analysis tasks, since no separate documentation staff was allotted.

In summary, the Phase 1 Program Joint SIWG developed and executed the NASA and RSC-E engineering activities necessary to successfully enable joint operations between the two largest orbital vehicles in existence. Engineering methods and solutions were jointly developed and applied to thoroughly assess the technical aspects of the Shuttle-*Mir* missions. Several of these methods and solutions advanced the state of the art in their respective fields and are being used today to design and plan International Space Station (ISS) missions, as well as in the design of ISS elements themselves. Also, as the individuals from each country worked together on problems and struggled with each other's language, they forged close personal and professional bonds. This spirit of personal and communal cooperation exhibited by all the individuals in the SIWG was critical to the success of our efforts. We hope that the cooperative personal and technical efforts of this joint Phase 1 Program working group will be useful and educational to engineers working on all future space programs.

3.2 Structure/Process/Organization Relationships

To conduct joint activities in preparation for Shuttle missions to *Mir*, WG-3 was established with co-chairmen designated from NASA and RSC-E. The co-chairmen directed the overall joint operations and engineering integration activities necessary for planning and conducting the joint Shuttle-*Mir* missions. The combination of the operations and integration specialists from NASA and RSC-E into the same working group was crucial to the success achieved during the joint program.

The systems integration component of WG-3 was divided into technical teams that encompassed the following basic areas of responsibilities on all missions:

- Spacecraft Physical Characteristics
- Active and Passive Thermal Control Systems
- Life Support Systems
- Avionics, Audio, and Video Systems
- Mated Flight Control Systems
- Approach, Docking, Mated, and Separation Loads (including Structural Modeling)
- Thruster Plume Definition

NASA and RSC-E engineering specialists were selected as co-leaders for the technical teams. The co-leaders were responsible for the preparation of joint documentation that defined the requirements, constraints, and limitations for the Shuttle and the *Mir*.

Each subgroup co-chair was responsible for certifying that his/her respective spacecraft was compatible with the joint requirements for a given mission, and each signed a certificate of flight readiness for each joint mission, for the appropriate technical area. Following subgroup flight certification, the WG-3 co-chairs signed and submitted to the program managers a group flight readiness certificate.

3.3 Joint Accomplishments

3.3.1 STS-63 Integration

The first Shuttle flight to rendezvous to close proximity with *Mir* successfully tested and demonstrated Shuttle piloting techniques, range sensor performance, docking target lighting, and *Mir* maneuver to docking attitude capabilities. A centerline TV camera was simulated in the Spacehab overhead window and provided excellent views of the docking target. The Shuttle Ku-band radar, the Handheld Laser and the Trajectory Control System (TCS) laser systems demonstrated the capability to track the *Mir* Station. The air-to-air VHF voice communications systems were also demonstrated.

3.3.2 STS-71 Integration

Planning for the first two joint missions, STS-71 and STS-74, presented some of the greatest challenges and accomplishments. Top-level agreements for operating Shuttle and *Mir* together set the stage for subsequent missions and were key to the success of the program. Piloting and docking the Shuttle to *Mir* involved considerations in jet thruster firing loads and contamination, and accuracy of piloting techniques, while studying approach relative position and velocities required to obtain capture. Positioning *Mir* for a Shuttle approach involved feathering and rotating *Mir* solar arrays to minimize impacts from jet plumes and shutting down systems to conserve power as a result. The control of the mated Shuttle/*Mir* vehicle became the primary responsibility of Shuttle, as a natural consequence of Shuttle's "renewable" propellant source on each flight. Lighting, communication, and thermal constraints influenced joint vehicle attitude decisions. The *Mir* environments shared by the crews in Shuttle and *Mir* were augmented by Shuttle's capabilities to produce oxygen (O2) and nitrogen (N2) and the design of transfer methods across hatches. Hardware designs and movement of equipment acceptable to both sides accomplished audio and visual crew communication to U.S. and Russian mission operation centers.

One of the early engineering challenges was to design the Shuttle/*Mir* docking interface that would allow safe mating of both vehicles. A location for the docking was chosen to maximize both Shuttle performance and cargo bay space for supporting modules/hardware and maximize clearance/minimize environmental impacts between vehicles. A design that tied together the external airlock with the Spacelab module was optimized using a series of tunnel sections and unique integration hardware (bridges, ducts, etc.). A number of existing program tunnel sections were utilized for Phase 1. Most, if not all, of this hardware will be used for the ISS Spacehab resupply missions.

3.3.3 STS-74 Integration

The Shuttle/*Mir* mated configuration for STS-74 was completely redefined. When RSC-E informed NASA that the Kristall module/docking port had to be repositioned from its temporary location on the X-axis to its permanent location along the Z-axis, the new Shuttle/*Mir* configuration had to be re-engineered. "Clocking studies" were performed to determine the best mix of physical clearances, thermal constraints, communication needs, loads, attitude control, contamination, plume impingement, piloting, and remote manipulator subsystem (RMS) operations. The success of the subsequent Phase 1 missions demonstrated that a key criteria considered for these early analyses was defining a mated configuration that would last throughout the Phase 1 program.

In between the STS-71 and STS-74 missions, RSC-E successfully returned the Kristall module to its permanent location using the mechanical arm. RSC-E designed the DM as an extension to the Kristall docking port to provide adequate clearances between the Shuttle and *Mir* solar arrays. There were major challenges involved for both NASA and RSC-E to accomplish integration of the DM into the Orbiter on an accelerated flight template including: joint data exchanges, manufacturing and testing in Moscow, delivery and testing at Kennedy Space Center (KSC), and satisfying NASA safety requirements with minimum analysis/design change. Joint cooperation was key to jointly determining and agreeing upon the optimum locations for NASA docking aid hardware on the DM (and docking system) that would serve Shuttle docking for both STS-74 and subsequent flights. These included lights, cameras, trajectory control sensor (TCS) retro-reflectors, primary and secondary targets, and the Shuttle vision system targets. STS-74 demonstrated the use of docking aids/cues for the remaining missions.

Berthing the DM to the Orbiter docking system with the RMS, and docking the combined vehicle was successful, demonstrating that joint data exchange was accomplished, and pre-mission engineering and planning were accurate. Power transfer between androgynous peripheral assembly system (APAS) systems was performed smoothly. Both APAS units and DM systems operated nominally. STS-74 proved to be nearly identical to the on-orbit berthing operations that would be required on the first ISS joint mission.

3.3.4 Docking Module Integration

Integration and operations planning for delivering the Russian DM aboard Shuttle to the *Mir* Space Station was accomplished successfully in a very short time. It is to RSC-E's credit that they designed, manufactured, tested, and delivered the DM to the U.S. in 18 months. There may be some education in hardware development for NASA, since few changes were made to the design as a result of analytical validations performed by NASA. It is to NASA's credit that the Shuttle launch and on-orbit integration requirements were clearly transmitted, Russian engineering processes were understood, and — with a compressed mission cycle — the right engineering information was extracted to perform an enormous amount of analytical work to deal with safety and verification issues in the Shuttle standard integration process. Dedicated individuals at JSC and KSC performed the right studies and analyses, sharing the results with RSC-E counterparts. NASA performed design thermal and loads analyses and non-linear studies on individual hardware elements, participated in DM testing both in Moscow and in the U.S., integrated NASA hardware inside and out, planned RMS operations, and developed crew procedures as well as other integration activities. KSC did an outstanding job of planning and executing ground operations, while managing to land a Russian plane on the Shuttle landing strip, house and transport Russian personnel, and smooth the entry and exit of various RSC-E test personnel.

There was great cooperation at the project engineering level. RSC-E appointed a Chief Designer to head the project at RSC-E, emphasizing the significance and importance of the program. Mr. I. Efremov's effective managerial and technical abilities ensured success in this monumental task of building a new *Mir* module and designing it to be compatible with a foreign transportation vehicle in a very compressed time frame. NASA appointed a dedicated Shuttle lead to oversee all areas of mission integration. The efforts of RSC-E and NASA project personnel, test engineers, operations planners, and analysts were outstanding, given the cultural barriers and ambitious schedule for delivering and integrating the DM with the Shuttle.

NASA and RSC-E engineers jointly accomplished the task of installing U.S. hardware inside the DM for later crew removal. Defining Russian hardware that the crew would interface with under both nominal and contingency situations took patience and fortitude. SVS targets were added after the DM design was complete. These targets allowed early ISS Program (ISSP) testing of a new berthing tool that will be used to construct the ISS.

The DM, which was carried up and berthed to the *Mir* on STS-74, was powered, commanded, and monitored via Shuttle systems while it was in the Shuttle cargo bay as well as when it was berthed to the Orbiter docking system (ODS). For STS-74, joint document 3411 was the program agreement for delivering DM to *Mir*. This document defined all technical requirements for interfacing the DM with the Shuttle, as well as the Shuttle environments (thermal, loads, etc.) which the DM would be subject to during ascent and an orbit. The DM was transitioned to *Mir* power and control while docked, and remained on the *Mir* as the new docking interface for Shuttle.

3.3.5 Vehicle Attitude Control

3.3.5.1 Shuttle

A significant challenge during the Shuttle/*Mir* program was the successful docking of the Shuttle and *Mir*. The Shuttle crews performed the relative translational control manually, but the Shuttle and *Mir* autopilots were required to maintain precise rotational orientations. Previous experience had demonstrated the effects of the Shuttle control on Shuttle proximity piloting, but the effects of the *Mir* control system on this operation were unknown.

Models of the *Mir* control system were developed and implemented in Shuttle piloting simulations to analyze the effects on piloting and plume. These models became invaluable in understanding the effects of various activities that occurred on *Mir*, including a brief period of dual control on STS-81.

Shuttle/*Mir* proximity operations were complicated by the fact that the Russian docking mechanism required high closing velocities to ensure capture. These high closing velocities would make precise control of the docking difficult for the crew and would result in unacceptably high docking loads. Procedures and software were designed to allow a slower, more precise approach to be flown with low contact velocities. This was achieved by developing software that performed an automatic series of firings that were initiated by the crew at vehicle contact to drive the docking mechanisms into a latched state. This software upgrade was implemented on a fast track schedule to be available for the first Shuttle/*Mir* docking flight.

The successful Shuttle attitude control of the mated Shuttle/*Mir* stack represented a significant milestone in the Shuttle program. The mated vehicle was the largest spacecraft ever orbited in space (~500K lb). STS-71 was the first flight of a large space structure (the Shuttle/*Mir* stack) with the potential for significant control-structures interaction. The vehicle was flexible, with dominant structural modes near the Shuttle control bandwidth. The Phase 1 program demonstrated that a series of Orbiter control system upgrades, developed to provide control of large, flexible, space structures, worked successfully and could be relied upon to provide control during the critical early assembly flights of the ISS. The Shuttle also demonstrated that it could control a variety of mated configurations with widely varying mass properties and structural flex characteristics. The control system had to meet stringent loading constraints, while providing robustness to uncertainties in the modeling of the rigid body mass properties and flexible dynamics.

3.3.5.2 *Mir*

The basic tasks performed by the *Mir* motion control system in joint flights were as follows:

- development of the attitude control timeline and preparatory operations before docking with the Shuttle;
- support of motion control system passive mode in controlling stack attitude from the Shuttle;
- verification of capability and support of stack attitude control;

- Performance of tests and technical experiments.

To support Shuttle approach and docking in all joint flights, the *Mir* motion control system supported the following operations:

- Inertial coordinate system correction using Kvant module star sensors with an inertial system setting precision no worse than 10 angular minutes;
- Maneuver of the *Mir* from the inertial coordinate system to baseline attitude for docking (such as the orbital coordinate system);
- Maintenance of orbital coordinate system attitude until mechanical capture;
- Movement of solar array panels to position required for docking;
- Forced desaturation of gyrodyne total kinetic moment to zero value;
- Transition to passive mode until mechanical capture is achieved.

All of the above operations were carried out nominally in all joint flights with automatic motion control, system control and with crew assistance.

During stack attitude control using the Shuttle vernier reaction control system, the *Mir* motion control system was in passive (indicator) mode. During passive mode, attitude control jets were blocked from firing both by the software and by an electrical interlock, and a gyrodyne kinetic moment value in a sphere with radius of 500 nms was provided.

The attitude of the *Mir*-Shuttle stack during various joint flights was controlled for the purpose of demonstrating the *Mir* motion control system capability to execute stack attitude control maneuvers using the attitude control jets and to maintain stack attitude using the gyrodynes. During an off-nominal situation for the Shuttle control system on STS-89, the *Mir* motion control system took over attitude control at MCC-H request.

During stack control there were from 9 to 11 gyrodynes in the control loop. Various jet configurations for control were used.

3.3.6 Vehicle Dynamics and Structures

Developing methods to dock and undock the vehicles and developing acceptable structural loading and strength for all operations was a key challenge with the influences of both vehicles. Shuttle pilot control of approach relative position and velocities, minimum jet firings, and docking contact accuracy was excellent. Docking capture was successful on the first try on each mission, with contact misalignments approximately one-third of their allowable limits. Shuttle plume loads on *Mir* were negligible. Attitude control of the joined vehicles used the very low load Shuttle vernier jets or the *Mir* gyrodyne systems. Only several hours of high load Shuttle primary jet control were performed to demonstrate its backup capability, since the vernier jets demonstrated good reliability by controlling attitude nearly the entire mission duration.

Structural modeling proved very accurate as demonstrated by the measured *Mir* response to Shuttle docking and structural dynamic excitation tests of the joined vehicles. Modeling updates were made to the Shuttle model based on on-orbit test data, while no updates to the *Mir* model were necessary. Shuttle plume loads on *Mir* were not verified by flight experience since they were so infrequent, low level, and sparsely recorded.

Crew exercise loads were significant, since the pace of ergometer and treadmill exercise excites natural frequencies of the structure. This exercise also uses significant structural life because of the extended duration required for crew health maintenance. To reduce a loss of resources, limits were placed on the amount of time the cosmonauts ran on the treadmill. Shuttle docking produced the highest loads on the module structure; this was deliberate to maintain a high capture probability. Structural life usage from docking was not significant, since the number of cycles was very low.

Mir structural life was a significant consideration since the *Mir* use had been extended beyond original design intent. A Progress vehicle collision with *Mir* between Shuttle flights damaged one *Mir* module and loaded other primary structures in a severe manner, giving additional incentive to reduce *Mir* structural life usage. Lack of detailed structural health inspection techniques for long-duration spacecraft remains a technical and [illegible]ment challenge.

Significant tools were developed to examine the structural reactions of two mated vehicles. Individual tools were developed to determine loads due to crew exercise, crew extravehicular activity (EVA) and intravehicular activity (IVA), and Shuttle-induced plume loading on *Mir* solar panels due to Shuttle venting. Loads spectra analysis tools that use Shuttle postflight jet firing histories allowed us to report *Mir* life usage after each mission. Crew exercise forcing functions were developed based on test data. (All these have applications for the ISSP.)

3.3.7 Shuttle Jet Plume Impingement

Minimizing the loading and a contamination effect from Shuttle jet plumes during docking and mated operations was a prime consideration with *Mir* large surface solar arrays in the vicinity. The knowledge of Shuttle jet plume effects while approaching and docking with vehicles was limited before Phase 1 and became crucial to the integration of both vehicles.

Extensive effort to develop plume models for Orbiter reaction control subsystem (RCS) environment was accomplished through the use of chamber tests, on-orbit tests, and analysis. In particular, the Shuttle Plume Impingement Flight Experiment provided the plume environment data needed to develop a math model which accounted for the effects of scarfed nozzles and plumes from the simultaneous firing of two close-proximity thrusters. Significant tool development was performed, which greatly increased our analytical capability for modeling plumes and their impingement upon orbiting vehicles.

3.3.8 STS-76 Through STS-91 Real-Time Changes

Vehicle physical and environmental changes became a continual challenge in the *Mir* program. Continual changes to *Mir* configuration — such as Spektr/no Spektr, Priroda/no Priroda, Progress/no Progress, solar array orientations, thermal constraints, and newly identified (or delivered) hardware — gave NASA a constant challenge in mission planning and verification. RSC-E had to deal with Shuttle configuration/mass differences due to mission payload changes from Spacelab to DM to Spacehab. NASA added new airlock venting plumes and possible RCS jet leakage events to RSC-E's environments to consider. All these engineering challenges were successfully met.

The successful flexibility of the two programs in dealing with changes to each succeeding mission cannot be overemphasized. Sometimes events aboard *Mir* during the months before or during a flight required significant data exchange, negotiation, and replanning on both sides. Engineering studies and operating agreements to accommodate large anomalies, such as the Progress/Spektr collision, and small anomalies, such as the period of joint attitude control, were performed with no impact to the ongoing program. All Shuttle and *Mir* systems generally performed extremely well throughout each mission with few anomalies that affected joint operations. The flexibility exhibited by both programs before and during each mission is a good example of the maturity of the joint Shuttle/*Mir* program.

3.3.9 Active and Passive Thermal Control

Thermal control issues were prominent points of negotiation in arriving at joint mission plans acceptable to both sides. Differing thermal constraints for each vehicle challenged us to come to common agreements on attitudes; providing joint humidity control became a task in system operations management while maximizing water production capability.

Preflight negotiation of a mated stack attitude timeline was a major joint activity throughout the joint program. For each mission, the objective was to find an attitude sequence that was thermally acceptable to both the Shuttle and the *Mir*. In addition, the *Mir* solar array power production had to be considered in the negotiations. The priority was to find an attitude that met the needs of the *Mir* power and thermal requirements and the Shuttle passive thermal requirements. The Shuttle active thermal requirements were only considered if the total net water production was negative. Therefore, water transfer to the *Mir* was not the highest priority, since it was always difficult to meet the other three requirements. The discussion became unique for each mission because of the changes in vehicle configurations and the beta angle profile associated with each mission. In general, *Mir* thermal specialists preferred a solar vector parallel to the *Mir* X-axis (the base block long axis) in order to minimize the *Mir* cross-sectional area presented to the Sun. This would result in less solar energy absorbed by the *Mir* stack and less of a heat load to be rejected by the *Mir* active TCS. The importance of this "rule" was greater for missions at higher beta angles and greater if any element of the *Mir* TCS were out of operation (e.g., coolant loop down as a result of leakage). Shuttle passive thermal constraints prominent in the discussions included main landing gear tire minimum temperature limits, vernier RCS thruster minimum leak detection limit, external airlock extravehicular mobility unit water service line minimum and maximum temperatures, and the orbital maneuvering subsystem (OMS) oxidizer high-point bleed line minimum temperature limit. On the last two joint missions using Orbiters OV-105 and OV-103, respectively, the OMS oxidizer high-point bleed line issue disappeared with the removal of that hardware from those vehicles in preparation for ISS missions. In summary, all *Mir* and Shuttle passive thermal constraints were successfully protected throughout docked missions. Attitude timeline negotiations typically continued up to and after Shuttle launch for each mission, and some attitude adjustments were even negotiated after docking based on real-time data. Negotiations proved to be routine and successful.

A major accomplishment of the joint thermal activities was the successful integration of the Russian DM as Shuttle cargo. As a result of Joint Working Group discussions, DM system information was gathered that allowed the building of DM geometric and thermal math models. These models were used to perform DM design verification analyses as well as later mission verification analyses. The results were discussed with the Russian thermal specialists, to optimize the final design. The Shuttle provided electrical power to the DM during transport to *Mir* to maintain thermal control (circulates the ethylene glycol in the thermal control loops and add heater energy to these loops). The pre-mission thermal analyses predicted, and the STS-74 mission proved, that the DM could be successfully transported to and installed on *Mir* while protecting all DM thermal limits. The experience of integrating, analyzing, and transporting Russian cargo in the payload bay is felt by both sides to have laid important groundwork for upcoming ISS launch and assembly missions.

On each mission the Shuttle provided conditioned air to *Mir* through an air interchange duct (70 to 100 cfm). A booster fan and special bypass ducting was installed in the ODS maintaining the required airflow to other habitable volumes (Spacelab and Spacehab), while providing the agreed-to air flow to *Mir*. During STS-74, when the DM was installed on the ODS and the hatches opened for crew ingress prior to docking with *Mir*, the ODS ducting was used to establish and maintain a habitable environment in the DM in support of manned activities. Throughout all joint operations, thermal and humidity control of the exchanged air was accomplished by nominal stowed radiator control, deployed radiator control, and/or flash evaporator system (FES) activation. On STS-74, the FES was turned off (to save water) when the radiators were not controlling. After this mission, the Russians compared temperature and humidity data between STS-71 and STS-74, asked that the FES remain on for subsequent flights, for temperature and humidity control, and accepted the impact to water transfer.

On all Phase 1 missions, planning for water transfer required balancing attitude constraints for orbital debris protection, orbital heat rejection via the radiators, and orbiter passive thermal control. On earlier missions, special measures were taken thermally to boost the accumulation of water for transfer. In some cases, radiators were deployed during both predocked flight and docked flight to minimize the loss of water via the FES. For most of the missions, radiators were not deployed because of the increased risk of orbital debris penetration. When possible, predocked attitudes were selected to ensure thermal control by the radiators without the consumption of water by the FES. In general, on missions with higher Beta angles, the radiators were less effective in the 'debris-friendly' orbiter attitudes, and more water was required for FES cooling, and therefore less water was available for transfer. Leaving the FES on for air humidity and thermal control was given higher priority than water accumulation for transfer (with the exception of STS-74).

A final area of thermal activity was the verification of the various cargoes flown in the payload bay during these missions. In general, the primary payload bay occupants (like Spacelab, the DM, the ODS, and the Spacehab Single and Double Modules) were robust payloads using Shuttle services that were easily compatible with the joint missions. One modification did need to be made to the Spacelab water coolant lines to support the docked phase of STS-71: heaters were added to the lines to prevent freezing in case water flow was lost while docked with *Mir*. Normally, attitude control is used to prevent freezing in such a situation; however, while docked with *Mir*, attitude adjustment would not have been available to prevent coolant line freezing. Secondary payload bay occupants, including the Russian APAS, the TCS, and the European Space Agency proximity operations sensor, also had thermal limits of concern. Either attitude selection and/or real-time operational intervention avoided all thermal limit violations.

3.3.10 *Mir* Lithium Hydroxide (LiOH) Hardware

The regenerable carbon dioxide (CO2) system in the Kvant 1 module was unable to operate to its full capacity due to an ethylene glycol leakage in the cooling system. Hardware to assist in the removal — to maintain safe levels of CO2 in the Kvant 1 module — was developed and delivered on STS-74. The hardware had to be constructed such that air flow through the charcoal bed of the LiOH canister would occur first, since the LiOH might degrade some of the compounds to toxic products if they were not initially removed by the charcoal. Special adapters were constructed to attach the LiOH cartridges to a fan on board the *Mir*, accomplishing the pushing of the airflow through the center of the cartridge radially outward through the charcoal bed and migrating to the LiOH bed. Written procedures accompanied the hardware instructing the crewmen on proper LiOH canister installation and replacement of the spent cartridge. Supplemental fresh LiOH cartridges were manifested on successive flights to assist in maintaining onboard CO2 levels.

3.3.11 Water Transfer From Shuttle to *Mir*

A significant engineering challenge was meeting the agreement to deliver 4600 kg of water to *Mir*, both potable and technical (hygiene, electrolysis, waste system flush). When carrying water as part of Shuttle's cargo didn't make sense from maximizing vehicle performance capability, a 'system' was devised to collect fuel cell by-product, and treat and transfer it to *Mir*. The water requirements could not be met by standard production of fuel-cell-generated water, either in quantity or quality.

For STS-71, a joint agreement with the Russians was established to transfer iodinated water from the Shuttle to *Mir* for use as technical water. NASA created hoses and adapters to allow for water transfer from the Shuttle galley auxiliary port to the CWC or to the EDVs. Two other types of hoses with quick disconnects on only one end were shipped to Russia. In Russia, hydroconnectors were added to the other end of the hoses. These hoses, one with a male hydroconnector and one with a female hydroconnector, were flown on a Progress flight to *Mir*. The hoses allowed the CWC to be emptied on *Mir* into the Russian water system and also allowed the Russian water tank on the Shuttle to be filled.

The water transferred to *Mir* during STS-71 was used for technical purposes only, because it contained iodine, which is used in the Shuttle water system as a disinfectant. The *Mir* potable water system uses silver for bacteria control and adds minerals for taste enhancement. When iodine and silver are combined in water, they form a precipitate; therefore, Shuttle water and *Mir* drinking water are not compatible.

For STS-74, a method for removing iodine and adding silver and minerals was developed to allow the delivery of potable water to *Mir*. IRMIS (iodine removal and mineral injection system) was created for that end, allowing the final concentration of silver and minerals in the CWC water to meet Russian water requirements. After postflight water analysis was completed, iodide presence in the water necessitated upgrading to the IRMIS system. IRMIS worked successfully from that point on.

The total amount of water transferred to *Mir* exceeded the goal of the contract. The transfer of water from Shuttle to *Mir* was a learning opportunity in terms of water management. One of the significant lessons learned was how much water can be made available if water transfer goals are incorporated into on-orbit attitude planning. Attitudes before and after docking can have a significant impact on the amount of water available for transfer. It is not just the docked attitudes that determine the amount of water available. The timeline for filling water bags can affect how much can be transferred; that is, allow ample time to fill as many as possible. If additional stowage locations can be found to store mote than four bags before docking, additional water can be transferred if the pre-docked attitudes are good radiator performance attitudes.

A practice learned from Energia was the removal of iodine from the water and the addition of alternative bio-control substances and minerals to the water. The removal of iodine has proven to be very timely as the Medical Office had raised an issue about iodine exposure to the crew during normal missions. The addition of minerals to the water is a technique the Russians use to insure their crew members do not become depleted in inorganic minerals during spaceflight.

Summary of Supply Water Transferred to *Mir*

Table 3.1

Flight	Summary	lb	Sample Results	Comments
71	3 CWC, 16 EDV	1067.4	Contained iodine	Re-processed on *Mir*
74	10 CWC	993.0	Failed iodide	Re-processed on *Mir*
76	15 CWC	1506.6	Passed	
79	20 CWC	2025.3	Passed	Reused 5 CWCs
81	16 CWC	1608.1	Passed	Reused 1 CWC
84	11 CWC	1038.0	Passed	1 half-filled CWC
86	17 CWC	1717.2	Passed	Reused 2 CWCs (81,84)
89	16 CWC	1614.9	Passed	Reused 1 CWC
91	13 CWC	1219.5	Passed	1 half-filled CWC
	Total:	12790.0 (5800.4 kg)		

3.3.12 Life Support Resources/Consumables Transfer

Mir Space Station O2 and N2 generation systems and CO2 removal systems were designed to normally support a crew of three. When docking missions were planned with crew work activities planned throughout Shuttle and *Mir*, mated air interchange and consumables planning became critical to the success of up to 10 crew members working and breathing in both vehicles. Shuttle capabilities were maximized to provide/boost the common atmosphere in both vehicles. Other factors contributed to the life support equation:

In the process of maneuvering to jointly acceptable docking attitudes and to minimize Shuttle jet plume impacts, the *Mir* solar arrays were often rotated and feathered in angles unfavorable to power production. *Mir* systems were turned off to conserve power use. The Vozdukh CO2 absorption system and the Electron O2 supply system were often not in operating mode during docking and sometimes during the joint mission. Joint planning and cooperation in life support were critical to providing a working environment. The Shuttle facilities were utilized to augment/maintain atmospheric pressure, humidity, and O2 and CO2 levels within tolerances for both vehicles.

NASA developed an integrated air exchange model as a tool to evaluate the integrated air interchange system capabilities, limitations, interface requirements, and operating constraints for each joint mission. Pre-mission analysis evaluated the N2, O2, CO2, and humidity conditions and allowed us to plan system usage and construct hardware required for transfer of consumables. After each mission, pressure and humidity conditions were measured. Preflight analyses results and postflight data comparison concluded that our tools were accurate and each mission was successfully planned and executed.

After docking Shuttle and *Mir*, the ODS vestibule was pressurized using *Mir* consumables, and leak checked. Pressurization from the lower pressure vehicle, the *Mir*, was necessary to prevent 'burping' of the *Mir* hatch. Opening the upper hatch valves of the Orbiter airlock then equalized the *Mir* and Shuttle volumes. The combined vehicle was pressurized by the Shuttle pressure control system and maintained at 14.7 psia until undocking. Careful management of N2 resources allowed Shuttle to provide the desired pressures.

Before undocking and before hatch closure, Shuttle resources were used to pressurize the combined volume. Nitrogen was used for *Mir* pressurization and O2 was used for the additional crew metabolic consumption during the docked phase and for raising the total partial pressure of *Mir*. We achieved the desired agreement of raising the *Mir* total pressure to 15.5 psia and partial pressure of O2 concentration to 25%.

Mir Pressurization Data

Table 3.2

Flight (STS)	*Mir* Docking Pressure (mmHg/psia)	*Mir* – Undock Pressure (mmHg/psia)	*Mir* – Undock PPO2 (mmHg/psia)	GN2 Transferred (lb)	GO2 Transferred (lb)
71		780.9/15.1		87.4	48.3
74	710/13.73	796.4/15.40	199.1/3.85	44.2	59.0
76	737/14.25	801/15.49	193.4/3.74	42.2	61.6
79	729/14.10	802/15.51	187.96/3.63	43.2	69.2
81	739/14.29	790/15.28	190.7/3.69	42.1	57.7
84	734/14.19	785/15.18	200.6/3.89	20.9	81.5
86	620/11.99	780/15.1	189.3/3.66	130.7	75.7
89	643/12.43	798.5/15.44	189.1/3.66	133.4	56.4
91	623/12.05	788.5/15.25	185.7/3.59	149.4	46.6
Total N2/O2 Transferred to *Mir*				693.5	556.0

3.3.13 Communication Systems

Air-to-air communications between vehicles for proximity operations were highly successful, providing voice communications at ranges significantly greater than required. Air-to-air communications between vehicles was provided by the use of existing VHF radios and antennas on the *Mir*. The Shuttle used a commercial transceiver which was tunable to *Mir* frequencies, a new audio-radio interference unit for integration into the Shuttle audio system, and a window-mounted antenna which was stowed during launch and landing. Air-to-ground tests were successfully conducted with *Mir* before the first flight use on STS-63.

The Ku-band system was used in radar mode for rendezvous and separation activities within previously agreed-to distances. It was reconfigured to communication mode for transmission and reception of voice, data, and TV. An obscuration mask was used during all docked operations to preclude irradiating the *Mir*. The Ku-band system operated nominally.

ODS centerline and truss-mounted closed circuit television cameras were used as the principle visual cues for docking and undocking with *Mir*. After docking, the Shuttle external airlock centerline TV connections were used to hook up a drag-through camcorder/speaker microphone system which contained multiple quick-disconnects on the cable to allow use of this system in any of the *Mir* modules. Performance of all of the TV systems was very satisfactory.

3.3.14 Spacecraft Physical Characteristics

The joint vehicle drawings, known as document 3402, were developed during STS-63 to identify the configuration and properties of each vehicle. The content was expanded at STS-71 to include mated Shuttle/*Mir* configuration and properties. Vehicle descriptions expanded to include mass properties, antenna & jet locations, docking target and camera locations, vents, lights and windows, and alternate configuration. All these critical physical attributes pertaining to both vehicles were required to perform mission planning and analysis. The 3402 document was used across the program by the Safety and EVA groups, and for crew familiarization. This document has been carried over to the ISSP.

3.4 Docking System

The docking system utilized during NASA-*Mir* joint flights provided reliable attachment and subsequent mechanical and electrical connections between the Shuttle and the *Mir* during Shuttle docking in manual mode. Following docking and hatch opening, it provided a pressurized pathway between vehicles.

The docking system for the Space Shuttle was developed on the basis of the АПАС-89 androgynous peripheral docking assembly (APDA), which had been developed for the Buran Orbiter. Two APDAs, installed on the Kristall module, have been on the *Mir* since 1990. Near the start of the Shuttle/*Mir* program preparatory period, the Soyuz TM-16, also equipped with an androgynous docking system, was mated with the Kristall module АПАС-89.

Nine Shuttle dockings with the *Mir* were carried out from 1995 through 1998 (STS-71, -74, -76, -79, -81, -84, -86, -89, -91). From 1993-1995, in preparation for STS-71, the RSC Energia designed, developed and flight-certified a docking system for the *Atlantis* Orbiter (OV-104). The Rockwell Company (now BNA) installed an APDA on the newly developed exterior airlock and integrated the system as a whole with other Orbiter systems (electric power, control, monitoring, and telemetry). The combined APDA and Orbiter systems were commonly referred to as the ODS. The APDAs, instruments, control console, and other hardware, as well as docking dynamics and strength, were developed and certified at RSC-E. The docking system components were integrated with the Orbiter components and were tested on an electrical mockup ("brassboard") of the Rockwell Company. Working jointly, NASA, Rockwell and RSC-E experts tested the docking system at Rockwell, performed preflight preparation at KSC, and provided for spaceflight mission support.

The Shuttle/*Mir* docking process for the *Mir* missions had seven phases of operation: deployment, capture, attenuation, extension, retraction, structural lockup and separation. The deployment phase begins when the docking mechanism guide ring is driven from its stowed position to its ready-to-dock position. In the ready-to-dock position, the mechanism capture latches are disengaged. The capture phase begins when the astronauts/cosmonauts maneuver the docking port of the Orbiter into contact with the *Mir* port. The orbiter interface is forced onto the *Mir* interface by the relative velocity between the vehicles and by an orbiter primary reaction control system (PRCS) jet-assisted maneuver. The thrusting maneuver is initiated manually by the orbiter crew once initial contact at the interface is detected by contact sensors (or when visual queues indicate that thrusting is safe). The immediate response of the orbiter, caused by the PRCS thrusting, forces the three guide ring petals on each APDA into alignment. The capture latches then engage, once the interfaces have been fully seated. Each of the three petals on the active interface is equipped with a latch assembly consisting of two capture latches. The three capture-latch assemblies are passively engaged. Each engages to a body mount on the passive mechanism and functions independently of the other two. The latches are designed so that the vehicles can safely separate in the event that only one or two latch assemblies engage. Once all three latch assemblies engage, all possible axes of rotation between the interfaces are removed and "soft-docking" has occurred. This completes the capture phase. The docking process switches to an automatic mode once capture has been sensed. Five seconds after capture latching, the hardware switches to a high-damp mode, which is intended to attenuate the relative vehicle motion in a deliberate manner. Prior to the high-damp mode, a load-limiting device prevents either vehicle from being overloaded during compression of the mechanism. After the high-damp mode has been initiated, the load-limiting device is no longer effective in limiting the loads.

After the relative vehicle motion has been arrested, the mechanism is slowly driven to a fully extended position. As the mechanism moves into its forward position, the relative vehicle misalignments, originally absorbed by the APAS, are driven out of the system. In the forward position, there is an operational delay as alignment indications are detected. Once the alignment indication is received, the retraction phase begins. Retraction starts as the mechanism locking devices are engaged. The locking devices keep the mechanism rigid and prevent relative vehicle misalignments from accumulating during retraction. As the retraction phase progresses, the vehicle structural interfaces are brought together and, once the final position has been detected, the structural lockup phase is initiated. As the passive and active structural hooks engage, the interface seals and separation devices are preloaded. For structural latching, there are two gangs of six structural hooks on each vehicle at the structural interface. Each gang of latches consists of a passive hook and active latch. Each active latch engages with the opposing passive hook. Once the latches fully engage, the structural interfaces are preloaded at the required level, and "hard-docking" has occurred. At the end of the mission, the tunnel is depressurized for undocking. The structural latches are disengaged, and the preloaded separation devices provide the impulse necessary to push the vehicles apart. Once the vehicles are a safe distance apart, the orbiter initiates a separation burn, completing the undocking operation.

STS-74 differed fundamentally from STS-71 in that it was necessary to dock with the Kristall module, which was at a *Mir* lateral berth. To do this, an additional docking module was created with two APDAs. The Orbiter APDA was a redesigned version with electrical interface connections to control two APDAs successively: first the APDA on the ODS and then the APDA on the docking module (through the interface connectors). The APDA with interface electrical connectors and a special switching device for switching control circuits was in the Orbiter for this mission. The entire configuration was successively developed and tested on the ground.

The docking procedures for STS-74 were more extensive than the other missions. The docking module aft APDA was berthed to the ODS APDA using the Orbiter remote manipulator arm. Subsequently, the docking module active APDA was controlled from the Orbiter through the APDA electrical connectors and was docked to Kristall. After undocking in flight STS-74, the docking module assembly remained as part of the *Mir*. All subsequent dockings were with the docking module APDA.

Missions STS 71 through STS-86 were carried out on the Orbiter *Atlantis*. The Orbiter *Endeavour* (OV-105) was prepared for mission STS-89 after the ODS was configured similarly to that of flight STS-74, with the control circuit switch. The APDA remaining from STS-71, modified with respect to interface electrical connectors, was used for this purpose. This configuration was developed in preparation for the first Orbiter flight in the ISS program (STS-88, flight 2A).

The Orbiter *Discovery* (OV-103) was prepared for the mission STS-91, with a modernized docking system designed for long-term use in the ISSP. This system uses the so-called "soft" APDA, with the new adaptive shock-absorbing system, ensuring substantially lower loads during docking. The control system of this assembly was altered accordingly, and the piloting procedure revised.

All 9 dockings and subsequent undockings were implemented completely and virtually without problems, in nominal modes. As a result, during Phase 1 the rightness of the designs, joint operations organization methods, approach to certification, hardware preparation, and piloting procedures, as well as crew and ground personnel training, were completely confirmed.

3.5 Lessons Learned/Applicability to ISS

3.5.1 Structure and Process

The organizational structure in which the operations and engineering integration specialists from NASA and RSC-E were combined into the same working group was crucial to the success achieved during the program. It was extremely valuable that NASA and RSC-E specialists responsible for the various technical disciplines worked directly with each other. A similar structure should be considered for ISS application.

The first rendezvous mission (STS-63), the first docking mission (STS-71), and the first assembly mission (integration, transportation, and on-orbit assembly of the DM on STS-74) exercised many of the engineering integration and operations that will be required for ISS launch and assembly missions. The remaining Shuttle missions to *Mir* further developed and refined these methods. The experience obtained by both NASA and RSC-E managers and engineering specialists in preparation for and during these missions will be invaluable as they apply their experience to the upcoming ISS missions.

3.5.2 Vehicle Dynamics, Structures and Attitude Control

The Shuttle readiness to support ISS for on-orbit operations in the vehicle dynamics, structures and control integration technical area is complete. Performance of essentially all functions (rendezvous and proximity operations, docking, mated vehicle attitude control and loads) has been successfully demonstrated. The Shuttle/*Mir* missions utilized the docking system hardware and on-orbit operations that will be required on ISS missions. Also, the Orbiter control system upgrades, developed to provide control of large, flexible space structures, worked successfully and can be relied upon to provide control during the critical early assembly flights of the ISS.

Just as with the Shuttle control system, the *Mir* motion control and navigation system performed the task of controlling the attitude of a stack with a mass close to 250 tons. The problems of control caused by the lack of rigidity of such a design were successfully solved. Control was provided both by vernier thrusters and gyrodynes. The simultaneous setting of the inertial coordinate system which was performed during several experiments on the Shuttle and *Mir* enabled a procedure to be developed for tying in the coordinate systems of the modules comprising the station. A procedure was developed for the correction of the inertial coordinate system of the *Mir* using data concerning the status vector received from the Shuttle. The experience accumulated during the performance of the tasks listed above will be used to solve analogous tasks facing the ISS.

3.5.3 Life Support and Thermal Control

During Shuttle-*Mir* program flights, the rightness of decisions made regarding integration of the life support and thermal mode control systems was confirmed. The Shuttle environment control systems, with nominal ventilation between the *Mir* and the Shuttle, had no trouble maintaining atmospheric parameters in the combined volume within acceptable limits.

Experience gained may be used in ISS operations. This applies first of all to joint flights of the ISS with the Shuttle, but this experience will also be helpful also in integrating the American and Russian ISS segment systems.

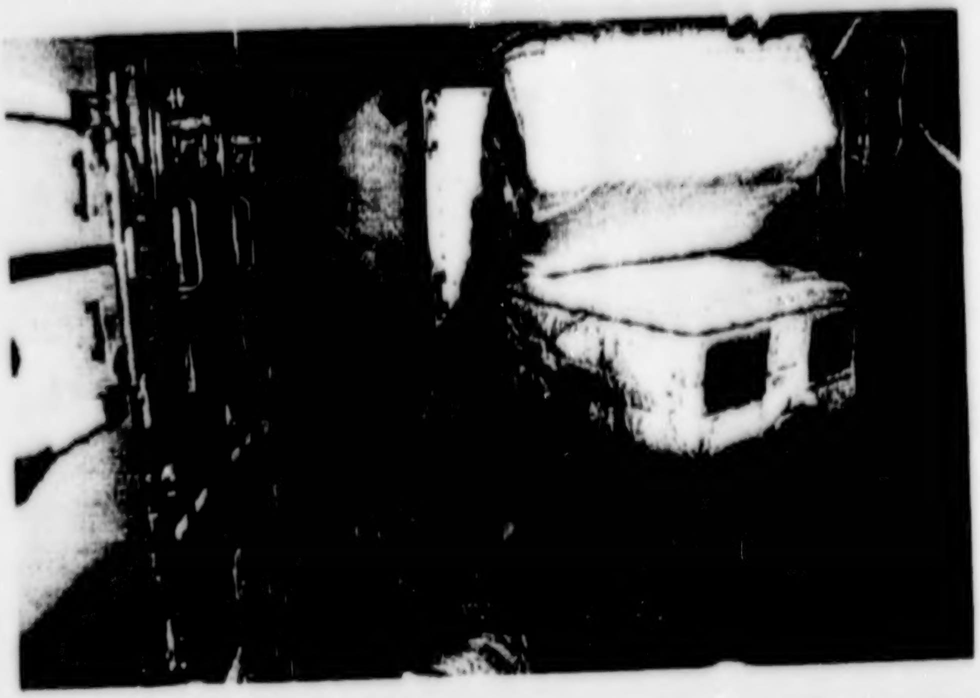
The hardware and operational techniques developed for water transfers to *Mir* are directly applicable to Shuttle/ISS water transfer. For the first five years of ISS assembly/operations, the techniques developed during Phase 1 for water transfer will be used for ISS.

3.5.4 Communications

The developed diagrams and documentation on the organization of communications during work in joint flights from STS-63 to STS-91 may be used in the future, and were the foundation for development of documents and operations on the ISS.

3.5.5 Tools and Operating Techniques

Engineering tool development and operating techniques were constantly improved during the program by both NASA and RSC-E in all technical areas. Obvious shortfalls were detected at the start of the program and better efficiencies were necessary as the time to prepare for each mission grew shorter. The Shuttle/*Mir* program challenged the efficiency of some existing engineering tools and created a demand for new tools to address mated vehicle operations. Many of these tools have applications for the ISSP.



STS-86 and STS-91 astronaut Wendy Lawrence performs transfer operations

Section 4 - Cargo Delivery & Return

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4.1 Summary Data on Cargo Delivered to/Returned From the *Mir* Under the *Mir* Shuttle/*Mir*-NASA Programs

While implementing these two programs, nine Shuttle vehicles docked with the *Mir* station (STS-71, -74, -76, -79, -81, -84, -86, -89, -91).

The Shuttle vehicles delivered **22,893.33 kg** of cargo to the *Mir*, including:

1. Docking module docked to the Kristall module – **4,096.22 kg**.
2. Russian cargo with a total mass of **8,627.14 kg**:
   - Food containers with food rations – ***2,515.56 kg***.
   - Outfitting hardware – ***4,015.56 kg*** (gyrodynes, storage batteries, current converters, and hardware for the following systems: Elektron-V, Vozdukh, thermal control system [TCS], telemetry, communications, computer complex, etc.)
   - Hardware to support extended manned flight – ***1,709.70 kg*** (LiOH cartridges, hardware for atmospheric analysis, individual hardware and cosmonaut equipment, personal hygiene aids, solid waste containers, water tanks, medical kits, flight data files, packages for cosmonauts, etc.);
   - Hardware to perform repair-maintenance work – ***242.42 kg*** (sealants, tools, special kits for maintenance work on the Elektron-V and Vozdukh systems, the TCS, the Spektr module, etc.);
   - Scientific experiments hardware – ***143.90 kg***
3. Water from Shuttle systems – **5,805.46 kg**.
4. Oxygen and nitrogen – **567.04 kg**.
5. American scientific hardware – **3,768.44 kg**, including hardware to support joint crew activities.
6. CNES hardware – **29.03 kg**.

The Shuttle vehicles returned **7,839.32 kg** of cargo from the *Mir* station, including:

1. Russian cargo with a total mass of **3,284.90 kg**.
   - Scientific experiment hardware and various data carriers – ***314.68 kg*** (film, video cassettes, diskettes, dosimeters, Greenhouse hardware, the Incubator-1M control and monitoring module, egg container-holder, container with Komza cassettes, various samplers, etc.)
   - Hardware to conduct research after extended use onboard the station, refurbishment, and re-use – ***2,532.65 kg*** (gyrodynes, teleoperator remote control mode (ТОРУ) hardware, Kurs, the Kvant-V system, Krater-V hardware, Alice equipment, communications equipment, hardware for the Elektron-V, Vozdukh, TCS, etc.);
   - Empty food containers for loading American food rations and repeat use – ***296.09 kg***;
   - Equipment and cosmonauts' preference items, symbols, etc. – ***141.48 kg***.

2. American scientific hardware – **4,479.72 kg**.
3. ESA hardware – **55.86 kg**.
4. DARA hardware – **7.74 kg**.
5. CNES hardware – **11.1 kg**.

Progress M (№ 224, 226, 227, 230, 231, 232, 233, 234, 235, 237, 236, 240, and 238) vehicles delivered **453.97 kg** of American scientific hardware to the *Mir* station.

Soyuz TM (№ 73 and 75) vehicles delivered **4.97 kg** of American scientific hardware to the *Mir* station.

The Spektr module delivered **705.47 kg** of American scientific hardware to the *Mir* station.

The Priroda module delivered **856.91 kg** of American scientific hardware to the *Mir* station.

The total mass of American scientific hardware delivered to the station onboard the Spektr and Priroda modules and the Soyuz TM and Progress M vehicles is **2,021.32 kg**.

Data on Cargo Traffic to the *Mir* on Shuttle Vehicles (*Mir*-Shuttle/*Mir*-Nasa Programs)

Table 4.1

Year	Flight №	Shuttle №	Delivered			Returned	
			Russian hardware, kg	Water, kg	American scientific hardware, kg	Russian hardware, kg	American scientific hardware, kg
1995	01	STS-71 Spacelab	148.79	485 (technical)	78.51	326.17	121
	02	STS-74 Russian docking module	226.03	450.36 (50% technical; 50% drinking, condemned)	139.1	172.09	171.55 (U.S.) 9.12 (ESA)
1996	03	STS-76 (single module) Spacehab	860.27	684.9 (365-technical; 320-drinking)	477.23	331.85	115 (U.S.) 22.54 (ESA)
	04	STS-79 (double module) Spacehab	890.05	920.6 (559-technical; 360-drinking)	591.5	410.73	328 (U.S.) 238.1 (U.S. Misc.) 23.7 (ESA)
1997	05	STS-81 (double module) Spacehab	969.1	729.4 (50%-technical; 50%-drinking)	626.4	403.7	682.1
	06	STS-84 (double module) Spacehab	1,171.16	470.8 (50%-technical; 50%-drinking)	562.6	600.76	549.1 (U.S.) 7.74 (DARA) 1.1 (CNES)
	07	STS-86 (double module) Spacehab	1,948.3	778.5 (50%-technical; 50%-drinking)	660.6	419.6	707.5 (U.S.) 10 (CNES)
1998	08	STS-89 (double module) Spacehab	1,477.28	732.5 (50%-technical; 50%-drinking)	594.2	300.22	804.87 (U.S.) 0.5 (ESA)
	09	STS-91 (single module) Spacehab	936.16	553.4 (270-technical; 283-drinking)	38.30 (U.S.) 29.03 (CNES)	319.78	762.50
		Σ Mass	Σ8,627.14	Σ5,805.46	Σ3,768.44 (U.S.)	Σ3,284.90	Σ4,479.72 (U.S.)
					29.3 - (CNES)		Σ55.86 - (ESA)
							Σ11.1 - (CNES)
							Σ7.74 (DARA)

Note 1: The cargo traffic data in this table was taken from the Working Group joint postflight reports.

Note 2: Flight STS-71 performed under the *Mir*-Shuttle program.

4.2 List of Russian Cargo on Shuttle Flights to the *Mir* Station

The tables below contain detailed data on the Russian hardware delivered and returned on Shuttle vehicles during the *Mir*-Shuttle and *Mir*-NASA programs.

Russian cargo delivered on STS-71 (*Mir*-Shuttle program)

Table 4.2

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
IELK (*Mir*-19)	115-9104-300	1060	550	400	2	80.00	1
Payload container (includes: 2 food containers with food rations - ΣMASS 14.47kg. УТЭ, personal items (*Mir*-19).	355ГК.3000А71-0	850	510	440	1	35.00	2
Food container (with food rations)	17КС.7860.200-01	380	305	123	1	8.79	3
Bracelet article (*Mir*-19)	К17.00.000.00	170	110	60	2	0.60	4
Personal dosimeter ИД-3М (*Mir*-19)	Хт2.805.602, IBMP-CPD-001	42	40	11	2	0.10	5
Sealing package	355ГК.4000-0	400	300	100	1	2.00	6
Cutting tool (for extravehicular activity, or EVA)	77КСО.1751А-0	1450	335	62	1	20.00	7
Wrench (for tightening screws on the Docking and Internal Transfer and System surface)	11Ф732.Г40002-0-04-11	203	50.8	d9.5	1	0.20	8
Supplemental FDF (*Mir*-19)	-	203	250	76	1	1.00	9
Gripper (tool for opening the APDA ring structural hooks)	33У.6516.003	485	170	30	1	1.10	Various hardware
Σ MASS						**148.79**	
WATER transferred						**485**	
Oxygen						**35.2**	
Nitrogen						**40.0**	

Russian cargo returned on STS-71 (*Mir*-Shuttle Program)

Table 4.3

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
Kentavr article (*Mir*-18)	К39.00.000.00	375	255	90	3	3.30	1
Remote Control Operator Mode (TOPY) Equipment							
Single-phase static converter ПОС-80РН	ИЖЕА.435.137.004	248	186	96	2	6.00	2
KX97-010M Device	КХ2.517.000	448	334	130	2	19.40	3
Translation and attitude control unit (БУПО)	11Ф615.8372А55-0	306	285	114	1	9.56	4
Power supply unit (БПС)	17КС.30Ю2311-0	359	185	284	1	7.88	5
Radio transmitter unit КЛ-108М	ГЭ2.015.226	315	250	114	1	4.80	6
Command generating unit (БФК)	11Ф615.8353А-0А55	375	230	211	1	7.94	7
Power switching unit БСК-1В	17КС.10Ю2704-0	221.5	194.5	76	2	3.56	8
Power switching unit БСК-2В	17КС.10Ю2706-0	221.5	194.5	76	1	1.74	9
Power switching unit БСК-5В	17КС.10Ю2708-0	221.5	194.5	76	1	2.04	10
Power switching unit БСК-7.5	17КС.10Ю2709-0	221.5	194.5	76	1	1.90	11
Power switching unit БСК-14	17КС.10Ю2713-0	221.5	194.5	76	2	3.48	12
11M617-1 Unit (ЦВУС-5)	ХА3.030.073	588	256	261	1	24.90	13
MC57301 Device, Buffer computer interface (ПМО)	ЩИ3.057.127	301	195	49	7	18.24	14
ШA294 transmitter unit	ИЮ2.017.289	585	395	140	2	38.50	15
Storage Battery (800A)	ИКШЖ.563534.007	465	278	530	1	74.00	16
Radio station "Korona SK"	ИХ2.000.221	135	125	115	1	2.92	17
Dosimeter assembly	IBMP-PRD-001	42	40	11	5	0.15	18
IELK (*Mir* 18)	115-9104-300	1060	550	400	2	41.10	20
Package of personal items (*Mir* 18)	-	230	200	100	2	4.00	21
TA963A-16 instrument	ИЮ2.158.045-14	190	260	300	1	11.80	22
Power switching unit БСК-5	17КС.10Ю2707-0	221.5	194.5	76	1	1.92	23
Set of books and souvenirs	-	550	300	200	1	7.70	24
Film and video cassettes	-	342.9	203.2	203.2	1	3.60	25
Handle (tool for opening APDA hatch)	11Ф732.Г1021-0А	200	100	100	1	0.64*	Various hardware
Gripper (tool for opening APDA ring structural hooks)	33У.6516.003	485	170	30	1	1.10*	Various hardware
IELK (NASA 1)	115-9104-300	1060	550	400	1	24.00*	Various hardware
Σ MASS						**326.17**	

Remark:

* - These items transferred to NASA after the flight.

Russian cargo delivered on STS-74

Table 4.4

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
Docking Module (DM) with solar arrays	**316ГК.0000-0**	**5094**	**4902**	**4510**	**1**	**4096.22***	
Set of EDV containers	355ГК.0010А74-0	643	d334	d230	1	11.20	1
EDV cover assembly	11Ф615.8711-180А151		d330	105	6	20.70	2
EDV adapter	11Ф615.8711-100А15	140	60	d40.5	1	0.30	3
EDV fill indicator	11Ф615.8711-210А15-1	47	d19	-	1	0.01	4
Food container (with Russian food rations)	17КС.7860.200-01	380	305	123	21	132.40	5
Crew Family Package (*Mir*-Shuttle Program, Phase 1)	-				1	4.97	Various hardware
Set of adapters (adapter - 17КС.2061-0, 2 ea.)	355ГК.003.А74-0	195	160	95	1	0.58	Various hardware
Clamps	17КС.2062-10-10 17КС.2062-10-20 17КС.2062-10-30				6	0.00	Various hardware
***Cargo in the Docking Module*:**							
Personal Hygiene Aids (СЛГ)	Хт4.160.603	225	120	140	10	9.50	
Personal Hygiene Aids (СЛГ-3)	Хт4.160.603-01	225	120	140	25	21.25	
Personal Hygiene Aids (СЛГ-Д)	Хт4.160.603-07	220	120	145	12	5.40	
Personal Hygiene Aids (СЛГ-Д)	Хт4.160.603-11	235	120	145	2	1.20	
Hair care item	Хт4.160.640	225	140	120	2	0.80	
Package of sanitary surface wipes	Хт4.160.003	225	140	120	2	2.00	
Kameliya-S athletic underwear	К19.00.000.00	330	230	40	24	7.92	
Komza cassette container	Фд.3.394.017-050	157	238	124	2	7.80	
∑ MASS						**226.03A**	
WATER transferred						**450.36**	
Oxygen						**26.80**	
Nitrogen						**20.09**	

Remark:

A - Total mass is based on the results of a weight check when transferring responsibility for cargo at Kennedy Space Center (KSC).

* The mass of the DM with the solar arrays (316ГК.0000-0) is shown for reference and has not been calculated into the mass for this table.

Russian cargo returned on STS-74

Table 4.5

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
МАГ-70 film case	-	-	d60	85	1	0.20	1
A-12 film case	-	-	d30	70	3	0.10	2
35 mm film case	-	-	d36	52	7	0.20	3
Komza cassette container	Фд 3.394.017-050	157	238	124	1	3.00	4
CA-20M film case	-	385	d305	355	2	44.00	5
Package with UN flag	-	320	90	90	1	0.10	6
ША294 transmitter unit	ИЮ2.017.289	400	142	597	1	19.00	7
TA082 Signal conditioning unit (БНУ)	ИВЯФ 468173.049	216	180	86	1	2.00	8
Vacuum valve unit (БВК)	17K.8711-0	318	267	241	5	35.00	9
Vacuum pump	17K.8710-300	330	206	104	3	21.00	10
Food container (empty)	17KC.7860.200-01	380	305	123	17	17.00	11
"Astra-2" experiment diskettes (3.5" - 4 ea. And 5.25" - 3 ea.)	-	140	140	51	1	0.30	12
HI-8 video cassettes (ALICE)	-	61	114	114	3	0.30	13
Greenhouse control unit	KM01.010.00	381	216	114	1	4.20	14
Greenhouse lighting unit	KM01.010.02.00	368	191	362	1	9.80	15
Betacam SP video cassettes	BCT-30MA	282	114	175	9	3.00	16
Cosmonaut Preference Kit	-	230	200	100	4	10.00	Various hardware
KAB 6180 container (atmospheric moisture condensate 0.15L)	10360.6180.000	-	d82	193	1	0.50	Scientific hardware
Egg container-holder	101896-500				1	2.00	Scientific hardware
Dosimeter assembly	IBMP-PRD-001	42	40	11	7	0.21	Scientific hardware
Dosimeter assembly	IBMP-APD-001	110	63	21	1	0.18	Scientific hardware
Σ MASS						**172.09A**	

Remark:

A - Total mass is based on the results of a weight check when transferring responsibility for cargo at KSC.

Russian cargo delivered on STS-76

Table 4.6

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
Bracelet article (NASA 2)	K17.00.000.00	170	110	60	1	0.3	1
IELK (NASA 2)	115-9104-300	1060	550	400	1	36.00	2
"Analysis-3" unit	KM09.066.00.00	215	110	20	1	0.35	3
"Analysis-3" hose	77KCO.8210.100	850	d24.3		1	0.12	4
Food container (with food rations)	17KC.7860.200-01	380	305	123	36	221.00	5
Set of EDV containers	355ГК.0010А74-0	643	d334	d230	2	23.00	6
EDV cover assembly	11Ф615.8711-180A151		d330	105	12	42.40	7
EDV adapter	11Ф615.8711-100A15	140	60	d40.5	2	0.60	8
EDV fill indicator	11Ф615.8711-210A15-1	47	d19	-	2	0.02	9
Storage Battery (800A)	ИКШЖ.563534.007	465	278	530	3	228.8	10
Current converter (ПТАБ-1)	ЕИГА.435.241.001-01ТУ	380	320	186	3	39.60	11
"Inkubator-1M" control and monitoring module	KM10.064.00.00	355	308	355	1	10.00	12
Personal Hygiene Aids (СЛГ)	Хт4.160.603	225	120	140	14	13.10	13
Personal Hygiene Aids (СЛГ-3)	Хт4.160.603-01	225	120	140	35	29.50	14
Personal Hygiene Aids (СЛГ-Д)	Хт4.160.603-06	220	120	140	10	3.40	15
Personal Hygiene Aids (СЛГ-Д)	Хт4.160.603-07	220	120	145	5	1.90	16
Penguin-3 suit	KH-9030-400	330	200	170	3	9.30	17
Kameliya-S athletic underwear	K19.00.000.00	330	230	40	20	6.70	18
Г16-М unit (gyrodyne) with fasteners	355ГК.0020А76-0	1040	d635	-	1	125.00	19
CA-20M film case	-	385	d305	355	2	58.60	20
Individual dosimeter ИД-3М (NASA 2)	Хт2.805.602, IBMP-CPD-001	42	40	11	1	0.05	21
Soft bag (Cosmonaut Family Package)	11Ф615.Б11710-0A55	340	310	90	2	9.70	Various hardware
Σ MASS						**860.27A**	
WATER transferred						**684.9**	
Oxygen						**35.2**	
Nitrogen						**20.0**	

Remark:

A - Total mass is based on the results of a weight check when transferring responsibility for cargo at KSC.

Russian cargo returned on STS-76

Table 4.7

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
К1-ВКА-03 instrument with three РТ-ВКА instruments	ЯУ2.000.031	696	460	390	2	148.91	1
ПТС-250АТ-2 instrument	2АТ.949.098	290	255	135	2	10.12	2
2Ф4-ВКА instrument	ЯУ3.468.011	214.5	124	42	2	2.09	3
Г16М unit (gyrodyne) with fasteners	355ГК.0020А76-0	1040	d635	-	1	120.53	4
МАГ-70 film case	-	-	d60	85	2	0.20	5
A-12 film case	-	-	d30	70	4	0.05	6
35 mm film case	-	-	d36	52	13	0.20	7
Cargo boom beam fragment	77КСТ.1220.01	-	d164	300	2	1.13	8
Food container (empty)	17КС.7860.200-01	380	305	123	37	37.00	9
"Vozdukh" system drying unit reversible valve	17К.8721-0				1	2.18	10
Cosmonaut Preference Kit	-	230	200	100	2	9.76	Various hardware
KAB container (with condensate)	10360.6180.000		d82	193	2	0.76*	Scientific hardware
∑ MASS						**331.85A**	

Remark:

A - Total mass is based on the results of a weight check when transferring responsibility for cargo at KSC.

* - The mass of the KAB container (10360.6180.000) is not considered in this table.

Russian cargo delivered on STS-79

Table 4.8

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
Bracelet article (NASA 3)	K17.00.000.00	170	110	60	1	0.14	1
Individual dosimeter, ИД-3М (NASA 3)	Хт2.805.602, IBMP-CPD-001	42	40	11	1	0.025	2
IELK (NASA 3)	115-9104-300	1060	550	400	1	34.10	3
Nitrogen purging unit	17КС.210Ю.1801-ОГУ	321	277	240	1	10.50	4
Food container (with food rations)	17КС.7860.200-01	380	305	123	37	238.53	5
Set of EDV containers	355ГК.0010А74-0	643	d334	d230	2	22.99	6
EDV cover assembly	11Ф615.8711-180А151		d330	105	12	41.00	7
EDV adapter	11Ф615.8711-100А15	140	60	d40.5	2	0.64	8
EDV fill indicator	11Ф615.8711-210А15-1	47	d19	-	2	0.023	9
Vacuum valve unit (БКВ)	17К.8711А-0	295	200	221	2	15.00	10
Personal Hygiene Aids (СЛГ)	Хт4.160.603	225	120	140	14	13.20	11
Personal Hygiene Aids (СЛГ-3)	Хт4.160.603-01	225	120	140	35	28.10	12
Personal Hygiene Aids (СЛГ-Д)	Хт4.160.603-06	220	120	140	10	3.45	13
Personal Hygiene Aids (СЛГ-Д)	Хт4.160.603-07	220	120	145	5	1.95	14
Penguin-3 suit	КН-9030-400	330	200	170	3	9.99	15
Kameliya-S athletic underwear	K19.00.000.00	330	230	40	20	6.72	16
Training loads harness (ТНК)	ТНК-У-1-1321_000	360	260	180	1	1.54	17
Athletic shoes (NASA 3)		340	140	100	1	0.82	18
CA-20M film case	-	385	d305	355	2	55.93	19
Storage Battery (800A)	ИКШЖ.563534.007	465	278	530	3	226.63	20
Current converter (ПТАБ-1)	ЕИГА.435.241.001-01ТУ	380	320	186	3	39.60	21
Penguin-3 suit	КН-9030-400	330	200	170	2	6.00	22
Soft bag (Cosmonaut Psychological Support Package)	11Ф615.Б11710-0А55	340	310	90	1	2.23	23
Soft bag (Cosmonaut Family Package)	11Ф615.Б11710-0А55	340	310	90	2	8.54	24
Letters	-				3	0.00	25
Г16-М unit (gyrodyne) with fasteners	355ГК.0020А76-0	1040	d635	-	1	122.40	26
Σ MASS						**890.05A**	
WATER transferred						**918.5**	
Oxygen						**42.0**	
Nitrogen						**12.5**	

Remark:

A - Total mass is based on the results of a weight check when transferring responsibility for cargo at KSC.

Russian cargo returned on STS-79

Table 4.9

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
Kentavr article (NASA 7)	К39.00.000.00	375	255	90	1	1.10	1
K1-BKA-03 instrument with three PT-BKA instruments	ЯУ2.000.031	696	460	390	2	148.70	2
ПТС-250АТ-2 instrument	2АТ.949.098	290	255	135	2	10.00	3
2AOK1-BKA instrument	ЯУ2.008.050	256	242	62	2	3.45	4
Air sampler - B (single-use)	-	259	114	102	6	3.77	5
Air sampler - ВД (extended use)	-	302	157	102	4	4.54	6
Air sampler - AK-1 (package with absorbent)	Хт4.160.007	150	50	10	3	0.30	7
Kvant-V system	ИЮ1.381.311	580	474	370	1	46.77	8
МАГ-70 film case	-	-	d60	85	2	0.41	9
A-12 film case	-	-	d30	70	2	0.00	10
35 mm film case	-	-	d36	52	11	0.20	11
Individual dosimeter ИД-3М	Хт2.805.602	42	40	11	2	0.23	12
CA-20M film case	-	385	d305	355	2	53.73	13
Komza cassette container	Фд.3.394.017-050	157	238	124	1	3.73	14
Food container (empty)	17КС.7860.200-01	380	305	123	35	29.27	15
Krater-V oven	У12.983.020	830	430	405	1	69.36	16
Krater-V control unit (ONIKS)	У12.390.305	342	246	172	1	5.64	17
Cosmonaut Preference Kit	-	230	200	100	2	2.91	18
БУ ДПО unit	77КСО.2310-0	220	220	155	2	6.77	19
ЛБ-1 unit	ИХ2.000.216	327	285	161	2	13.82	20
Gyrodyne attachment ring	355ГК.0020А76-101		d635	170.5	1	4.40	21
LIV video tape recorder	BVW-35P	348	296	140	1	6.63	22
Russian blood samples	-				4	0.23*	Scientific hardware
Orlan-DMA space suit cover-package	2АК-9000-6000-03 2АК-9803-300	1130	670	550	1	77.73*	Various hardware
Σ MASS						**415.73A**	

Remark:

A - Total mass is based on the results of a weight check when transferring responsibility for cargo at KSC.

* - The mass of these items is not included in the total for this table. NASA transferred the blood samples and the Orlan-DMA space suit after the flight.

NASA 2 (Shannon Lucid) returned individual equipment

Table 4.10

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
Penguin-3 suit (NASA 2)	KH-9030-400	330	200	170	1	3.09	
"Forel" suit (NASA 2)	Г-9101-700	420	410	130	1	3.73	
"Sokol KV-2" space suit (NASA 2)	2AC-9000-1000	520	440	260	1	11.04	
Σ MASS						**17.86**	

Remark: NASA transferred all items after the flight.

Russian cargo delivered on STS-81

Table 4.11

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
Bracelet article (NASA 4)	K17.00.000.00	170	110	60	1	0.14	1
IELK (NASA 4)	115-9104-300	1060	550	400	1	34.80	2
Individual dosimeter ИД-3М (NASA 4)	Хт2.805.602, IBMP-CPD-001	42	40	11	1	0.05	3
Food container (with food rations)	17КС.7860.200-01	380	305	123	49	319.51	4
Set of EDV containers	355ГК.0010А74-0	643	d334	d230	2	22.97	5
EDV cover assembly	11Ф615.8711-180А151		d330	105	12	41.13	6
EDV adapter	11Ф615.8711-100А15	140	60	d40.5	2	0.45	7
EDV fill indicator	11Ф615.8711-210А15-1	47	d19	-	2	0.03	8
Personal Hygiene Aids (СЛГ)	Хт4.160.603	225	120	140	26	24.95	9
Personal Hygiene Aids (СЛГ-3)	Хт4.160.603-01	225	120	140	6	4.95	10
Personal Hygiene Aids (СЛГ-Д)	Хт4.160.603-06	220	120	140	27	9.22	11
Personal Hygiene Aids (СЛГ-Д)	Хт4.160.603-07	220	120	145	5	2.04	12
Penguin-3 suit	КН-9030-400	330	200	170	6	18.01	13
Kameliya-S athletic underwear	K19.00.000.00	330	230	40	35	11.53	14
Training loads harness (ТНК)	ТНК-У-1-1321_000	360	260	180	3	4.59	15
Athletic shoes	-	340	140	100	1	0.75	16
Sleeping bag СПМ-2МН	170-9061-00		d260	370	4	14.26	17
CA-20M film case	-	385	d305	355	2	57.48	18
Storage Battery (800A)	ИКШЖ.563534.007	465	278	530	3	227.95	19
Current converter (ПТАБ-1)	ЕИГА.435.241.001-01ТУ	380	320	186	2	32.55	20
Г16-М unit (gyrodyne) with fasteners (including the ring)	355ГК.0020А76-0	1040	d635	-	1	125.40	21
Soft bag (Cosmonaut Psychological Support Package)	11Ф615.Б11710-0А55	340	310	90	1	1.91	22
Soft bag (Cosmonaut Family Package)	11Ф615.Б11710-0А55	340	310	90	2	4.23	23
Komza cassette container	Фл.3.394.017-050	157	238	124	1	2.37	24
Letters	-				3	0.00	25
LiOH - CO2 scrubbers (USA)			d172.7	287	9	28.62*	26
Mir orbital complex external configuration training aid		304.8	228.6	25.4	1	1.14	27
ALICE adaptive frame	355ГК.0040А81-101				1	7.85	Temporary transfer
Σ MASS						**969.1 A**	
WATER transferred						**729.4**	
Oxygen						**26.2**	
Nitrogen						**19.1**	

Remark:

A - Total mass is based on the results of a weight check when transferring responsibility for cargo at KSC.

* - The mass of the U.S. CO2 scrubbers (9 ea.) is not considered in the total mass of this table.

Russian cargo returned on STS-81

Table 4.12

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
Kentavr article (NASA 7)	К39.00.000.00	375	255	90	1	0.86	1
K1-BKA-03 instrument with three PT-BKA instruments	ЯУ2.000.031	696	460	390	2	148.90	2
ПТС-250АТ-2 instrument	2AT.949.098	290	255	135	2	10.66	3
2AOK1-BKA instrument	ЯУ2.008.050	256	242	62	1	1.72	4
PT-BKA instrument	ЯУ2.998.054	114	96	30	1	0.27	5
KX97-010M instrument	KX2.517.000	448	334	130	1	10.76	6
Single-phase static converter (ПОС-80РН)	ИЖЕА.435.137.004	248	180	95.5	1	2.95	7
Signal transformer unit (БПС)	17КС.30Ю2311-0	359	185	284	1	8.04	8
Translation and attitude control unit (БУПО)	11Ф615.8372А55-0	306	285	275	1	9.58	9
БУ ДПО unit	77КСО.2310-0	220	220	155	2	6.95	10
CA-20M film case	-	385	d305	355	2	49.00	11
Optic and electronic unit (ALICE)	F/ALI/91/001-002	950	600	320	1	63.50	12
Container of "Antares" thermostats (ALICE)	F/FLI/91/003	540	430	300	1	27.00	13
Package of supplemental components (ALICE)	-		d250	80	1	1.18	14
AMPEX-733 video cassette	-	295	180	55	1	1.32	15
Removable cassette container СКК-9	Э10934-090-0	255	215	42	1	1.90	16
Removable cassette container СКК-10	Э10934-090-0	255	215	42	1	1.90	17
МАГ-70 film case	-	-	d60	85	1	0.09	18
A-12 film case	-	-	d30	70	2	0.04	19
35 mm film case	-	-	d36	52	15	0.32	20
Individual dosimeter ИД-3М (NASA 3)	Хт2.805.602	42	40	11	1	0.04	21
Pressure differential regulator (РПД)	17КС.21Ю.6086-0		d210	125.4	1	2.36	22
Vacuum pump	17К.8710-300	330	206	104	1	7.20	23
Vacuum valve unit (БВК)	17К.8711А-0	298	205	222	1	7.40	24
Food container (empty)	17КС.7860.200-01	380	305	123	34	31.90	25
Cosmonaut Preference Kit	-	230	200	100	2	3.50	26
Gyrodyne attachment ring	355ГК.0020А76-101		d635	170.5	1	5.40	27
KAB 6180 container (atmospheric moisture condensate)	10360.6180.000	-	d82	193	4	1.59*	Scientific hardware
Σ MASS						**403.7A**	

Remark:

A - Total mass is based on the results of a weight check when transferring responsibility for cargo at KSC.

* - The mass of the KAB 6180 container is not considered in the total mass of this table.

NASA 3 (John Blaha) returned individual equipment

Table 4.13

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
IELK (NASA 3)	115-9104-300	1060	550	400	1	32.36	
Penguin-3 suit (NASA 3)	KH-9030-400	330	200	170	3	9.14	
Sleeping bag CIIM-2MH (NASA 3)	170-9061-00	370	d260	-	1	2.95	
Σ MASS						**44.45**	

Remark: NASA transferred all items after the flight.

Russian cargo delivered on STS-84

Table 4.14

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
Bracelet article	К17.00.000.00	170	110	60	1	0.09	1
IELK	115-9104-300	1060	550	400	1	34.00	2
Individual dosimeter ИД-3М	Хт2.805.602	42	40	11	1	0.045	3
Food container (with food rations)	17КС.7860.200-01	380	305	123	48	322.74	4
"Elektron-V" liquid unit with protective end caps	10134.5003.00.000 355ГК.0050 А84-0	1328	430	341	1	137.90	5
"Elektron-V" control unit	10134.4470.00.000	350	320	237	1	8.40	6
"Elektron-V" equipment package		220	180	80	1	1.40	7
"Vozdukh" equipment package		370	190	110	1	6.10	8
TCS equipment package			d400	230	1	8.77	9
Set of EDV containers	355ГК.0010А74-0	643	d334	d230	2	24.24	10
EDV cover assembly	11Ф615.8711-180А15-1		d330	105	12	41.40	11
EDV adapter	11Ф615.8711-100А15	140	60	d40.6	2	0.24	12
EDV fill indicator	11Ф615.8711-210А15-1		47	d19	2	0.08	13
Medical packages	Хт4.160.608-П4, Хт4.160.608-П5	225	145	75	2	0.46	14
Г16М unit (gyrodyne) with fasteners	355ГК.0020А76-0		1040	d635	1	125.00	15
Г15М unit	6АГ.369.641	465	310	306	1	25.15	16
Г16-5 unit	6АГ.369.835	571	300	200	1	21.00	17
Communications interface module (МСИ)	ХА3.035.122	250.5	150.5	85.5	1	3.35	18
Storage Battery (800А)	ИКШЖ.563534.007	465	278	530	3	227.62	19
Current converter (ПТАБ-1)	ЕИГА.435.241.001-01	380	320	186	1	13.17	20
Transmitter unit ША294	ИЮ2.017.289	585	395	140	1	19.20	21
Solid waste container (КТО)	А8-9060-500		453	d330	6	19.84	22
LiOH cartridges (USA)			d172.7	287	12	38.16	23
Personal Hygiene Aids (СЛГ)	Хт4.160.603	225	120	140	14	13.21	24
Personal Hygiene Aids (СЛГ-3)	Хт4.160.603-01	225	120	140	35	29.56	25
Personal Hygiene Aids (СЛГ-Д)	Хт4.160.603-06	220	120	140	10	3.41	26
Personal Hygiene Aids (СЛГ-Д)	Хт4.160.603-07	220	120	145	5	1.91	27
Penguin-3 suit	КН-9030-400	330	200	170	3	9.03	28
Kamelia-S athletic underwear	К19.00.000.00	330	230	40	35	11.67	29
Training Loads Harness (ТНК)	ТНК-У-1-1321_000	360	260	180	1	1.45	30
Athletic shoes		340	140	100	1	1.00	31
Sleeping bag СПМ-2МН	170-9061-00		d260	370	1	3.41	32
Package with absorbers for АК-1	Хт4.160.007	170	55	13	3	0.30	33
Package for solid-fuel oxygen generator (ТГК)	355ГК.0060А84-10 355ГК.0060А84-20		d250	300	1	1.96	34
Soft bag (Cosmonaut Psychological Support Package)	11Ф615.Б1710-0А55	340	310	90	1	5.22	35
Soft bag (Cosmonaut Family Package)	11Ф615.Б1710-0А55	340	310	90	2	10.67	36
Σ MASS						**1,171.16A**	
WATER transferred						**470.8**	
Oxygen						**22**	
Nitrogen						**18.5**	

Remark:

A - Total mass is based on the results of a weight check when transferring responsibility for cargo at KSC.

Russian cargo returned on STS-84

Table 4.15

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
Kentavr article	К39.00.000.00	375	255	90	1	0.55	1
К1-ВКА-35 instrument with three РТ-ВКА instruments	ЯУ2.000.036	696	460	390	1	74.45	2
К1-ВКА-03 instrument with one РТ-ВКА instrument	ЯУ2.000.031-03	696	460	390	1	71.55	3
ПТС-250АТ-2 instrument	2АТ.949.098	290	255	135	1	4.82	4
2Ф4-ВКА instrument	ЯУ3.468.011	214.5	124	42	2	2.18	5
"Elektron-V" liquid unit with protective end caps	10134.5003.00.000, 355ГК.0050 А84-0	1328	430	341	1	135.30	6
ЩА009 instrument	ИЮ2.007.016	280	80	170	1	2.40	7
Transmitter unit ЩА294	ИЮ2.017.289	585	395	140	3	57.90	8
СА-20М film case	-	385	d305	355	2	54.14	9
Digital User Exchange Unit (МОЦА-02)	ХА2.082.035	560.5	260.5	258.5	1	19.66	10
35mm film case	-		d36	52	6	0.18	11
AMPEX-733 cassettes	-	295	180	55	1	1.35	12
Individual dosimeter ИД-3М	Хт2.805.602	42	40	11	1	0.05	13
Filter FOA	10191.5274.000	230	d248		1	6.50	14
ЗПТ-1 filter	10133.4029.000	300	309	342	2	30.90	15
Solid Fuel Oxygen Generator with package	6477.000	720	280	235	1	9.72	16
Package with absorbers for AK-1	Хт4.160.007	170	55	13	1	0.10	17
Gyrodyne attachment ring	355ГК.0020А76-101		d635	170.5	1	4.39	18
"Skorost" facility combustion chamber	17КС.70Ю.1001-0	360	218	124	1	1.90	19
3.5" diskette with "Astra-2" experiment	-	104	104	4.0	3	0.05	20
Condensate Water Recovery System (СРВ-К2) pipe	-	1700, 350	d30, d8		1	2.00	21
Cosmonaut Preference Kit	-	230	200	100	2	1.16	22
Acoustic guitar	РСТ РСФСР 83-72	940	340	110	1	1.69	23
Food container (empty)	17КС.7860.200-01	380	305	123	63	117.82	24
КАВ container (with condensate)	10360.6180.000		d82	193	2	0.91*	Scientific hardware
Σ MASS						**600.76A**	

Remark: * - The mass of the KAB container (10360.6180.000) has not been considered in the total mass of this table.

A - Total mass is based on the results of a weight check when transferring responsibility for cargo at KSC

NASA 3 and NASA 4 (Jerry Linenger) returned individual equipment

Table 4.16

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
"Sokol KV-2" space suit, NASA 3 (John Blaha)	2AC-9000-1000	520	440	260	1	9.55	
"Sokol KV-2" space suit, NASA 4 (Jerry Linenger)	2AC-9000-1000	520	440	260	1	9.05	
Penguin-3 suit (NASA 4)	KH-9030-400	330	200	170	4	12.32	
Sleeping bag СПМ-2МН (NASA 4)	170-9061-00	370	d260	-	2	6.72	
Orlan-M space suit gloves	ГП- 10К-2-1060026	300	120	120	1 pair	1.14	
IELK cover (NASA 4)	115-9104-340				1	0.80	
Seat liner (NASA 4) from the IELK	ДМ Л				1	4.90	
Light cargo (NASA 4) from the IELK	ДМ Л				1	3.50	
Σ MASS						**47.98**	

Remark: NASA returned all items after the flight.

Russian cargo delivered on STS-86

Table 4.17

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
Bracelet article (NASA 6)	К17.00.000.00	170	110	60	1	0.15	1
IELK (NASA 6)	115-9104-300	1060	550	400	1	30.85	2
Individual dosimeter ИД-3М (NASA 6)	Хт2.805.602	42	40	11	1	0.025	3
Food container (with food rations)	17КС.7860.200-01	380	305	123	80	484.17	4
Air pressurization unit (БНП) (full)	11Ф732.Б1721-0А101	386	750	362	3	131.00	5
11М617-1 unit (ЦВУС-5)	ХА3.030.073	588	256	261	1	25.02	6
Set of EDV containers	355ГК.0010А74-0	643	d 334	d 230	1	11.15	7
EDV cover assembly	11Ф615.8711-180А15-1		d 330	105	6	20.35	8
EDV adapter	11Ф615.8711-100А15	140	60	d40.5	1	0.26	9
EDV fill indicator	11Ф615.8711-210А15-1	47	d 19		1	0.01	10
Solid waste container (КТО)	А8-9060-500	453	d 330		5	16.50	11
Vacuum valve unit (БВК)	17К.8711А-0	295	200	221	2	15.46	12
Г16М unit (gyrodyne) with fasteners	355ГК.0020А76-0	1040	d 635		1	122.58	13
Г15М unit	6АГ.369.641	456	340	306	1	25.20	14
Г16-5 unit	6АГ.369.835	571	300	200	1	20.70	15
Storage Battery (800А)	ИКШЖ.563534.007	465	278	530	9	682.25	16
Current converter (ПТАБ-1)	ЕИГА.435.241.001-01	380	320	186	2	26.58	17
Personal Hygiene Aids (СЛГ)	Хт4.160.603	225	120	140	25	23.47	18
Personal Hygiene Aids (СЛГ-3)	Хт4.160.603-01	225	120	140	40	33.74	19
Personal Hygiene Aids (СЛГ-Д)	Хт4.160.603-06	220	120	140	20	6.74	20
Personal Hygiene Aids (СЛГ-Д)	Хт4.160.603-07	220	120	145	5	1.85	21
Penguin-3 suit	КН-9030-400	330	200	170	5	16.07	22
Kameliya-S athletic underwear	К19.00.000.00	330	230	40	60	18.43	23
Training Loads Harness (ТНК)	ТНК-У-1-1321.000	360	260	180	1	1.51	24
Athletic shoes	-	340	140	100	1	0.81	25
Sleeping bag СПМ-2МН	170-9061-00		d 260	370	1	3.49	26
Operator restraints for repairing the solar array							
Base (with link rod)	Э77КСО-3157-520	600	460	235	2	8.50	27
Anchor	Э77КСО-3157-540	550	550	230	2	7.80	28
Rack	77КМ-3157-360	1350	500	60	2	1.79	29
Rod	Э77КСО-3157-550	996	132	40	2	3.60	30
Rack	Э77КСО-3157-300	270	d 100		2	1.09	31
Solar array repair parts:							
Beam	77КСО-5805-100	1280	470	400	1	18.31	32
Bracket (for Option № 2)	77КСО-5805-301	400	230	240	1	6.26	33
Mechanism for sealing the Solar array pod:							
Sealing cover with Mechanical Assembly and Accessories	-		d 800	581	1	66.40	34
Handle bar	77КСО-5806-300	760	155	135	1	2.80	35

Russian cargo delivered on STS-86 cont.

Table 4.17 cont.

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
Hull sealing equipment:							
Sealant Applicator	17КС.Б9640-0	620	420	230	4	44.54	36
Clamp	17КС.Б9329-5000	500	300	120	2	7.08	37
Package of flanges, 8 ea.	17КС.Б9329-5020	180	120	120	1	2.83	38
Package of flanges, 12 ea.	17КС.Б9329-5030	250	120	120	1	4.20	39
Clamp	17КС.Б9329-6000	300	260	250	2	5.63	40
Clamp	17КС.Б9329-7000	300	260	150	2	4.78	41
Brush	17КС.Б9329-240	375	140	50	2	0.83	42
Set of caps	17КС.Б9329-8000	300	210	300	1	6.60	43
Vacuum cleaner bags (USA)	SEG39123308-301				10	0.45	44
Soft bag (Cosmonaut Psychological Support Package)	11Ф615.Б1710-0А55	340	310	90	1	3.90	45
Soft bag (Cosmonaut Family Package)	11Ф615.Б1710-0А55	340	310	90	2	6.85	46
LiOH cartridges (USA)	-		d172.7	287	8	25.44	47
VHS video cassette with instructions for Spektr module repair	МГ-И	180	100	20	1	0.23	
Protective end caps with fasteners (for Elektron-V liquid unit)	355ГК.0050А84-50 355ГК.0050А84-20		d 353 d 380	71 155	1 1	6.45*	Temporary transfer
∑ MASS						**1,948.27A**	
WATER transferred						**780**	
Oxygen						**34**	
Nitrogen						**59**	

Remark:

* - The mass of the protective end caps with fasteners (for the Elektron-V liquid unit) has not been considered in the total mass for this table.

A - Total mass is based on the results of a weight check when transferring responsibility for cargo at KSC.

Russian cargo returned on STS-86

Table 4.18

Description	Designation	Dimensions			Unit weight	Qty	Total weight	Priority
		mm	mm	mm	kg	ea.	kg	№
Kentavr article	К39.00.000.00	375	255	90	1.10	1	1.10	1
Instrument K1-BKA-03 with one PT-BKA instrument	ЯУ2.000.031-03	696	460	390	69.50	1	71.50	2
2Ф4-BKA instrument	ЯУ3.468.011	214.5	124	42	1.05	1	1.10	3
Sorbent set	ССК 0697	410	250	230	6.5	1	5.90	4
"Elektron-V" liquid unit with protective end caps	10134.5003.00.000, 355ГК.0050А84-0	1328	430	341	134.1	1	138.05	5
"Elektron-V" control unit	10134.4470.00.000	350	320	237	8.5	1	8.15	6
Fan	17К.8710-380	367	d 120		4.00	4	14.90	7
11M617-1 unit (ЦВУС-5)	ХА3.030.073	588	256	261	28.00	1	24.70	8
Vacuum valve unit (БВК)	17К.8711А-0	295	200	221	7.3	2	14.20	9
ЩА003 unit	ИЮ2.000.166	710	576	270	46.6	1	47.45	10
HI-8 video cassette	E5-90-HMEX	110	75	20	0.10	4	0.40	11
Individual dosimeter ИД-3М (NASA 5)	Хт2.805.602	42	40	11	0.05	1	0.025	12
Gyrodyne attachment ring	355ГК.0020А76-101		d635	170.5	5.40	1	4.45	13
Food container (empty)	17КС.7860.200-01	380	305	123	1.00	55	55.00	14
Cosmonaut Preference Kit	-	230	200	100	3.00	3	8.25	15
Science Hardware Platform ПНА-2	17КС.2482-0	820	300	150	10.62	1	9.55	16
Science Hardware Platform ПНА-3	17КС.2483-0	820	300	150	17.85	1	11.90	17
AK-1 sampler	Хт4.160.007	150	50	10	0.1	1	0.05	18
Package of condensate samples	11Ф615.8615-0А15	310	100	60	0.21	1	0.21	19
Betacam SP video cassette	BCT-30MA	175	115	31	0.31	9	2.95	20
Σ MASS							**419.6A**	

Remark:

A - Total mass is based on the results of a weight check when transferring responsibility for cargo at KSC.

NASA 5 (Michael Foale) returned individual equipment

Table 4.19

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
IELK (NASA 5)	115-9104-300	1060	550	400	1	34.00	
Penguin-3 suit (NASA 5)	КН-9030-400	330	200	170	1	3.00	
Sleeping bag СПМ-2МН (NASA 5)	170-9061-00	370	d260	-	1	3.41	
Training Loads Harness (ТНК) (NASA 5)	ТНК-У-1-21.000	360	260	180	1	1.45	
Athletic shoes (NASA 5)	-	340	140	100	1	1.00	
ПК-14 flight suit	2АГ-9004-1000				1	1.75	
Clothing	-				-	?	Not inventoried
Operator coveralls	К41.00.000.00				3	2.10	
Package ИЗОГ № 53	Хт2.787.001				1	0.50	
Box with personal hygiene kit (Komfort-1)	Хт6.875.057 Хт2.945.602				1	1.00	
Σ MASS						**48.21**	

Remark: NASA transferred all items after the flight.

Russian cargo delivered on STS-89

Table 4.20

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
Bracelet article (NASA 7)	K17.00.000.00	170	110	60	1	0.15	1
IELK (NASA 7)	115-9104-300	1060	550	400	1	31.14	2
Individual dosimeter ИД-3M	Хт2.805.602	42	40	11	1	0.025	3
Food container (w/joint food rations)	17KC.7860.200-01	380	305	123	77	453.15	4
Air pressurization unit (БНП) (full)	11Ф732.Б1721-0А101	368	750	362	2	86.40	5
Set of EDV containers	355ГК.0010А74-0	643	d334	d230	2	22.40	6
EDV cover assembly	11Ф615.8711-180А15-1		d330	105	12	40.75	7
EDV adapter	11Ф615.8711-100А15	140	60	d40.5	2	0.54	8
EDV fill indicator	11Ф615.8711-210А15-1	47	d19	-	2	0.03	9
Solid waste container (KTO)	A8-9060-500	453	d330	-	4	13.28	10
Air conditioning unit (БКВ-3) with protective cover	KBO.6705.00.000	615	625	855	1	82.35	11
Compressor unit (БКВ-3)	KBO.1565.000-01	350	d200	-	1	24.99	12
11M617-10 unit (ЦВУС-5)	XA3.030.073	588	256	261	1	24.99	13
Central Exchange Module 11M617-2 (ЦМО) with 2 cables for the ЦМО	XA3.031.104	250.5	275.5	158.5	1	9.44	14
Soft trash bag (КБО)	11Ф615.8715-0А15-01	310	310	100	10	8.35	15
Г16M unit (gyrodyne) with fasteners	355ГК.0020А76-0	1040	d635	-	1	125.00	16
Г15M unit	6АГ.369.641	456	340	306	1	25.00	17
Г16-5 unit	6АГ.369.835	571	300	200	1	20.75	18
Storage Battery (800A)	ИКШЖ.563534.007	465	278	530	4	304.80	19
Current converter (ПТАБ-1)	ЕИГА.435.241.001-01	380	320	186	3	40.22	20
Personal Hygiene Aids (СЛГ)	Хт4.160.603	225	120	140	25	23.44	21
Personal Hygiene Aids (СЛГ-3)	Хт4.160.603-01	225	120	140	60	50.39	22
Personal Hygiene Aids (СЛГ-Д)	Хт4.160.603-06	220	120	140	20	6.97	23
Personal Hygiene Aids (СЛГ-Д)	Хт4.160.603-07	220	120	145	5	2.11	24
Penguin-3 suit	KH-9030-400	330	200	170	5	14.72	25
Kameliya-S athletic suit	K19.00.000.00	330	230	40	60	19.55	26
Training Loads Harness (THK)	ТНК-У-1-1321.000	360	260	180	1	1.50	27
Athletic shoes	-	340	140	100	1	0.90	28
Sleeping bag СПМ-2МН	170-9061-00	-	d260	370	1	3.31	29
Soft bag (Cosmonaut Psychological Support Package)	11Ф615.Б1710-0А55	340	310	90	1	5.88	30
Soft bag (Cosmonaut Family Package)	11Ф615.Б1710-0А55	340	310	90	2	9.25	31
Г15M unit	6АГ.369.641	456	340	306	1	25.50	32
Σ MASS						**1,477.28A**	
WATER transferred						**732.5**	
Oxygen						**25.64**	
Nitrogen						**60.6**	

Remark:

A - Total mass is based on the results of a weight check when transferring responsibility for cargo at KSC.

Russian cargo returned on STS-89

Table 4.21

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
Kentavr article (NASA 6)	К39.00.000.00	375	255	90	1	1.10	1
Г16М unit (gyrodyne) with fasteners	355ГК.0020А76-0	1040	d635	-	1	125.80	2
КЛ106А synchronizer	ТЭ2.050.956	263	244	218	1	6.10	3
Solar array panel (МСБ) in transport container	17КС.5810-0; 11Ф615.Б1700-500А55.37	1370	700	390	1	44.55	4
МАГ-70 film case	-	-	d60	85	8	1.05	5
A-12 film case	-	-	d30	70	22	0.50	6
35mm film case	-	-	d36	52	32	1.10	7
Compressor unit (БКВ-3)	КВО.1565.000-01	350	d200	-	1	22.30	8
Central Exchange Module 11М617-2 (ЦМО)	ХА3.031.104	250.5	275.5	158.5	1	9.10	9
11М617-1 unit (ЦВУС-5)	ХА3.030.073	588	256	261	1	25.00	10
СКК-11 cassette	Э10934-090-0	225	215	42	1	1.80	11
Fan unit BP-5	2АГ-7838-1000-02	130	240	170	1	2.15	12
"Platan-N" № 5 equipment	-	426	447	113	1	7.10	13
"Komplast" panel № 4	77КСД-7912-200	400	250	40	1	2.05	14
ИГЛА command processing unit (БОК)	37КЭ.2111-0	285	232	377	1	10.65	15
Individual dosimeter ИД-3М (NASA 6)	Хт2.805.602	42	40	11	1	0.05	16
AMPEX-733 video cassette	-	295	180	55	1	1.35	17
Food container (empty)	17КС.7860.200-01	380	305	123	5	5.10	18
Cosmonaut Preference Kit	-	340	310	90	3	12.97	19
Latch	77КСД-5361-200	90	75	60	1	0.45	20
Rod part	77КСД-5361-120	200	90	70	1	0.95	21
Bolt	-				1	0.00	22
Air conditioning unit (БКВ-3) protective cover	355ГК.0070А89-101	615	625	382	1	6.80	23
Condensate removal pump (НОК)	5033B	190	130	82	5	5.30	24
Betacam SP video cassette	BCT-30MA	175	115	31	14	4.00	25
HI-8 video cassette	E5-90HMEX	110	75	20	8	0.70	26
Parts					1	2.20	27
KAB 6180 container (atmospheric moisture condensate)	10360.6180.000	-	d82	193	3	1.15*	Scientific hardware
Σ **MASS**						**300.220 A**	

Remark:

* - The mass of the KAB 6180 container has not been considered in the total mass of this table.

A - Total mass is based on the results of a weight check when transferring responsibility for cargo at KSC.

NASA 6 (David Wolf) returned individual equipment

Table 4.22

Description	Designation	Dimensions			Qty	Total Mass	Priority
		mm	mm	mm	ea.	kg	№
IELK (NASA 6)	115-9104-300	1060	550	400	1	35.00	
Penguin-3 suit (NASA 6)	КН-9030-400	330	200	170	3	9.00	
Penguin-3 suit (*Mir* 24)	КН-9030-400	330	200	170	4	11.80	
Training Loads Harness (THK), (NASA 6)	ТНК-У-1-1321.000	360	260	180	1	1.4	
Σ MASS						**57.2**	

Remark: NASA transferred all items after the flight.

Russian cargo delivered on STS-91

Table 4.23

Description	Designation	Dimensions			Unit weight	Qty	Total weight	Priority
		mm	mm	mm	kg **T**	ea.	kg	№
Food container (with Russian food rations)	17KC.7860.200-01	380	305	123	7.00	40	271.42	1
Experimental food container (with Russian food rations)	17KC.260Ю 3200-0	380	305	123	7.00	3	19.76	2
Portable pressurization unit (БНП) (full)	11Ф732.Б1721-0А101	368	750	362	48.00	1	43.60	3
БНП pipe	17K.10292-520	-	d400	50	1.00	1	0.34	4
Set of EDV containers	355ГК.0010А74-0	643	d334	d230	11.50	2	23.55	5
EDV cover assembly	11Ф615.8711-180А151		d330	105	3.53	12	41.65	6
EDV adapter	11Ф615.8711-100А15	140	60	d40.5	0.28	2	0.60	7
EDV fill indicator	11Ф615.8711-210А15-1	47	d19	-	0.014	2	0.034	8
Solid water container (KTO)	A8-9060-500	453	d330	-	3.50	6	19.69	9
Soft trash bag (КБО)	11Ф615.8715-0А15-01	- 310)	d290 (310)	100	0.85	20	16.70	10
Г16-М unit (gyrodyne) with fasteners (including ring)	355ГК.0020А76-0	1040	d635	-	125.00	1	125.44	11
Г15М Unit	6АГ.369.641	465	340	306	25.50	1	25.14	12
Г16-5 Unit	6АГ.369.835	571	300	200	21.50	2	41.90	13
Storage Battery (800A)	ИКШЖ.563534.007	465	278	530	76.00	2	152.15	14
Current converter (ПТАБ-1)	ЕИГА.435.241.001-01ТУ	380	320	186	14.50	1	13.43	15
Personal Hygiene Aids (СЛГ)	Хт4.160.603	225	120	140	1.05	14	14.70	16
Personal Hygiene Aids (СЛГ-3)	Хт4.160.603-01	225	120	140	0.90	35	31.50	17
Personal Hygiene Aids (СЛГ-Д)	Хт4.160.603-06	220	120	140	0.45	10	4.50	18
Personal Hygiene Aids (СЛГ-Д)	Хт4.160.603-07	220	120	145	0.45	5	2.25	19
Biomagnistat	ЮГШИ.375523.002	400	d160	-	4.00	1	3.22	20
Heat insulated vacuum container (ТВК) (BIOKONT-T)	БТХ5.100.000	400	d170	-	2.50	1	2.30	21
ЯДРО-БАВ (NUCLEUS-BAS)	Хm4.160.667	200	100	70	2.50	1	2.13	22
РЕКОМБ-К (REKOMB-K)	БТХ4.100.000	150	100	100	0.50	2	1.32	23
"Biocorrosion" package	-	305	225	20	0.60	1	0.23	24
Diskette package (2 ea..) of the information system		104	104	10	0.05	1	0.05	25
Box with 3.5" diskettes, (7 diskettes)	-	104	104	40	0.19	1	0.23	26
Soft bag (Cosmonaut Psychological Support Package)	11Ф615.Б11710-0А55	340	310	90	2.7	1	2.74	27
Soft bag (Cosmonaut Family Package)	11Ф615.Б11710-0А55	340	310	90	5.00	2	10.73	28
Food container (with STS-89 food rations)	17KC.7860.200-01	380	305	123	7.00	5	29.62	29
Solid waste container (KTO)	A8-9060-500	453	d330	-	3.50	3	10.02	30
Personal Hygiene Aids (СЛГ-3) from STS-86	Хт4.160.603-01	225	120	140	0.90	20	16.87	31
Soft trash bag (КБО) from STS-89	11Ф615.8715-0А15-01	-	d290	100	0.85	10	8.35	32
Σ MASS						**209**	**936.164**	
WATER transferred					**41÷49**	**12.5 CWC**	**553.4**	
Oxygen							**24.3**	
Nitrogen							**65.7**	

Remark: **T** - Theoretical mass of a unit of hardware.

A - Total mass is based on the results of a weight check when transferring responsibility for cargo at KSC.

Note: Cosmonaut V. Ryumin delivered the Minolta Electronic Camera Diskette to *Mir* (0.02 kg).

Russian cargo returned on STS-91

Table 4.24

Description	Designation	Dimensions			Unit weight	Qty	Total weight	Priority
		mm	mm	mm	kg	ea.	kg	№
Kentavr article (NASA 7)	К39.00.000.00	375	255	90	1.10	1	1.10	1
Г16-М unit (gyrodyne) with fasteners	355ГК.0020А76-0	1040	d635	-	125.00	1	121.00	2
К1-ВКА-03 instruments with one РТ-ВКА instrument	ЯУ2.000.031-03	696	460	390	69.50	1	71.65	3
2Ф4-ВКА instrument № 5	ЯУ3.468.011	214.5	124	42	1.05	1	1.10	4
МОМС-2П power unit (БП)	М62.087.328	395	344	290	15.00	1	15.65	5
Gas analyzer control unit (БКГА)	37ГК.7881-0	515	273	220	8.50	1	9.55	6
Canon EOS 50E camera with attachments	-	150	90	50	2.12	1	2.15	7
Hasselblad camera with accessories (in a single package)	500 EL/M	350	270	250	6.00	1	4.15	8
35 mm film case	-	d36	52	-	0.04	4	0.125	9
Betacam SP video cassette	BCT-30MA	175	115	31	0.31	11	3.19	10
3.5'' diskette	-	95	95	3	0.02	4	0.10	11
AMPEX-733 video cassette	-	295	180	55	1.35	6	6.80	12
Cassette with 35 mm film for the Minolta camera	-	d25	40	-	0.04	4	0.125	13
Package of cable samples	-	300	200	100	2.00	1	0.30	14
ЗПЛ-1 cartridge	10133.4029.000	300	309	342	16.0	1	14.20	15
ПКФ cartridge	5269.00.00	239	d128	-	2.40	1	1.65	16
Harmful contaminant filter (ФВП) cassette	6469.000	115	d394	-	8.00	1	10.80	17
P-16 dosimeter	Em2.805.000	307	164	121.5	2.50	1	3.05	18
Experimental food container (collapsed)	17КС.260Ю 3200-0	380	305	16	1.00	3	2.15	19
Biomagnistat	ЮГШИ.375523.002	400	d160	-	4.00	1	3.22	20
Heat insulated vacuum container (ТВК) (BIOKONT-T)	БТХ5.100.000	400	d170	-	2.5	1	2.27	21
ЯДРО-БАВ (NUCLEUS-BAS)	Хm4.160.667	200	100	70	2.5	1	2.13	22
РЕКОМБ-К (REKOMB-K)	БТХ4.100.000	150	100	100	0.50	2	1.32	23
"Biocorrosion" package	-	305	225	20	0.60	1	0.14	24
Individual dosimeter ИД-3М. (NASA 7)	Хт2 805.602	42	40	11	0.05	1	0.025	25
Cosmonaut Preference Kit	-	230	200	100	3.00	2	9.30	26
11М617-1 unit (ЦВУС-5)	ХА3.030.073	588	256	261	28.0	1	24.95	
Acoustic guitar	РСТ РСФСР 83-72	940	340	110		1	1.69	
Penguin-3 suit	КН-9030-400	330	200	170		2	5.90	
КАВ 6180 container (atmospheric moisture condensate)	10360.6180.000	-	d82	193	0.50	3	1.15*	Scientific hardware
Σ MASS							**319.785**	

Remark: - * The mass of the KAB 6180 container has not been included in the mass of this table.

NASA 7 (Andrew Thomas) returned individual equipment

Table 4.25

Description	Designation	Dimensions			Qty	Total Mass	Remark
		mm	mm	mm	ea.	kg	
IELK (NASA 7)	115-9104-300	1060	550	400	1	31.36	
Penguin-3 suit (NASA 7)	КН-9030-400	330	200	170	4	12.00	
Sleeping bag СПМ-2МН (NASA 7)	170-9061-00	370	d260	-	1	3.32	
Athletic shoes (NASA 7)	-	340	140	100	1	1.00	
Clothing	-				-	-	
ПК -14 flight suit	2АГ-9004-1000				1	1.14	
Operator coveralls	К41.00.000.00				3	3.64	
Eating utensils (NASA 7)					-	0.23	
Σ MASS						**51.69**	

Remark: All items transferred by NASA after the flight.

Table 4.26

Summary of the mass of Russian logistics material components transported to *Mir* on the Shuttle

Program	**"*Mir*-Shuttle"**	**"*Mir*-NASA"**								
Shuttle Flight №	STS-71	STS-74	STS-76	STS-79	STS-81	STS-84	STS-86	STS-89	STS-91	Σ mass for 9 flights
Total delivered including, kg:	695.29	723.19	1592.17	1861.65	1,743.80	1,688.56	2,820.50	2,296.02	1,578.46	14,999.64
•Russian logistical hardware	148.79	226.03	860.27	890.05	969.10	1,171.16	1,948.30	1,477.28	936.16	8,627.14
•water	485	450.36	684.9	920.60	729.4	470.8	778.5	732.5	553.4	5,805.46
•gases	61.5	46.8	47.0	51.0	45.3	46.6	93.7	86.24	88.9	567.04
Returned Russian hardware, kg	326.17	172.09	331.85	410.73	403.7	600.76	419.6	300.22	319.78	3,284.90

Remark: Under the "*Mir*-NASA" program:

1. A total of 14,304.35 kg were delivered, including:
    - Russian logistical hardware – 8,478.35 kg;
    - water – 5,320.46 kg;
    - gases – 505.54 kg

2. 2,958.73 kg of Russian hardware were returned.

4.3 Unique Features of *Mir*-Shuttle and *Mir*-NASA Orbiter Flights With Respect to Russian Cargo Accommodation

Under the above two programs the Orbiter was used to deliver various cargo in support of the joint flights. The layout of the Orbiter vehicles depended upon the primary objectives of the vehicle's flight to *Mir*. Therefore, the *Mir*-NASA Program utilized the SPACEHAB module and the *Mir*-Shuttle Program used the Spacelab module to deliver most of the cargo requiring pressurized stowage.

Both the SPACEHAB and the Spacelab modules were considered payloads (PL) rather than Shuttle components. Both were capable of carrying powered equipment connected to the onboard power supply and passive stowage kits. Russian equipment, with the exception of the Russian docking compartment, did not require power from the onboard power supply system. The SPACEHAB module was utilized in the *Mir*-NASA Program because it was more suitable for cargo accommodation. The pressurized SPACEHAB module housed most of the Russian cargo carried on the Orbiter.

The stowage areas in the crew compartment (mid-deck), airlock, docking compartment (Orbiter docking system, or ODS) designed for small articles or articles directly related to flight were utilized as authorized by NASA's Phase 1 Program Office.

Russian cargo received special attention in the course of Orbiter flight processing due to the fact that flights by the Shuttle to deliver cargo to the orbital facility were different from its typical flights. Russian cargo was divided into those that required hard-mounting and those that could be accommodated in stowage bags and lockers. In the process, late-load logistics were defined. Large items and hard-mounted hardware were installed aboard the Orbiter without the benefit of containers but rather to special attachment locations using interface adaptive hardware. Small items or kits were accommodated in standard stowage (lockers, flight bags of various sizes) available aboard the Shuttle.

A joint working group of U.S. and Russian experts was formed to manage the large variety of Russian and U.S. cargo and their accommodations on the Shuttle. The group also tracked U.S. hardware flown on Russian vehicles.

4.3.1 *Mir*-Shuttle Program

4.3.1.1 STS-71

During the STS-71 Shuttle flight, Russian cargo was accommodated in all the pressurized compartments suitable for hardware stowage, including the mid-deck (crew cabin), internal airlock, ODS, the Spacelab module located in the vehicle's payload bay.

Standard lockers and Volume D underneath the cabin floor were used as mid-deck accommodation. Special flight bags were utilized for cargo stowage in the internal airlock and the ODS.

Spacelab cargo accommodation consisted of flight bags attached to the ceiling and standard lockers installed in special racks. A vertical module loading technique was available for the late delivery items which, although not used during this mission, was utilized during subsequent flights to load the SPACEHAB module at the launch pad.

NASA developed a Spacelab-based rigid support of a special design to accommodate the return of a storage battery (Unit 800A).

4.3.2 *Mir*-NASA Program

4.3.2.1 STS-74

STS-74 delivered the Russian docking module (DM) with the two solar arrays, which was accommodated in the Shuttle's payload bay. The DM was installed to the ODS with the help of the remote manipulator system.

The bulk of the logistics was accommodated in special bags on the floor of the pressurized DM.

Some of the cargo was located in the mid-deck where standard lockers, Volume D under the cabin floor, and a special tray attached to the cabin floor were used as accommodations.

Special flight bags were employed to hold cargo in the internal airlock and the ODS.

4.3.2.2 STS-76

The unique feature of the STS-76 flight was the pressurized SPACEHAB single module installed in the vehicle's payload bay. This was the vehicle's first *Mir*-NASA flight with this module. Conscientious work on the part of Spacehab, Inc., the SPACEHAB contractor, and RSC-E experts assured efficient accommodation and attachment of Russian logistics.

A hard-mount design using a double rack was specially developed to carry large heavy items (in excess of 190 kg), such as the gyrodyne (Unit Г16M) and IELK, and was successfully utilized in every flight until the end of the *Mir*-NASA Program. This required the SPACEHAB contractor to modify the design of the double rack and RSC-E to manufacture an adapter (the gyrodyne fastening ring). A second double rack was modified to carry the IELK in a transfer bag, developed with the assistance of Russian specialists.

Special interface adapter plates were developed by the SPACEHAB contractor to accommodate three storage batteries (Unit 800A) on the SPACEHAB aft bulkhead.

It is worthy of note that a significant portion of the Russian cargo was installed using the MVAK at the launch pad (800A units, IELK - individual equipment and liner kit, food containers, etc.). In the past, many of these items were not loaded at the launch pad because of their weight. All the procedures for installing Russian cargo at the launch pad were developed by the SPACEHAB contractor in conjunction with RSC-E. The resulting experience in the vertical loading of the SPACEHAB module was subsequently utilized in the course of processing for every *Mir*-NASA flight.

Small portions of the Russian logistics (7 delivery and 6 return items) were accommodated in the mid-deck using standard stowage.

4.3.2.3 STS-79

Originally, the plan was to launch STS-79 on August 1, 1996. However, since it was necessary to replace the solid rocket boosters, the mission was postponed until mid-September 1996.

The unique feature of this flight was the use of the SPACEHAB double module located in the payload bay of this Orbiter vehicle. This was the first Shuttle flight utilizing the SPACEHAB double module configuration. The increased internal envelope of the SPACEHAB module allowed accommodation of a larger amount of cargo, including Russian hardware. The double SPACEHAB configuration was utilized in all subsequent missions except STS-91.

NASA had not planned to accommodate any Russian cargo in the mid-deck during STS-79. However, because of SPACEHAB mass limitations, such accommodation was allowed (3 delivery and 5 return items). These items were stowed in mid-deck lockers.

Furthermore, in the course of preflight processing there appeared some items requiring urgent delivery to *Mir* (nitrogen purge unit, vacuum valve units, and additional Penguin-3 suits), which called for late delivery. The nitrogen purge unit was filled with nitrogen under pressure and installed into the SPACEHAB module immediately prior to its rollout from the SPACEHAB Payload Processing Facility (SPPF).

4.3.2.4 STS-81

For the STS-81 flight almost all the Russian logistics were stowed in the pressurized SPACEHAB double module. A small portion of the cargo (4 delivery and 2 return items) was accommodated in the mid-deck. It is worthy of note that, unlike STS-79, this flight had a new nominal cargo accommodation in SPACEHAB. This new stowage location was on the module's rear section sub-floor. It enabled additional hard-mounted cargo to be accommodated and transported by the Orbiter. It should be noted that this flight used Energia-developed adapters launched by the Orbiter for the purpose of hard-mounting returning hardware (ALIS equipment).

4.3.2.5 STS-84

In this case, the SPACEHAB double module was again the Orbiter's primary location for cargo. The unique feature of this flight's stowage was the use of new attachment hardware on the center sub-floor panel and the aft bulkhead in the rear of the module. Thus, the SPACEHAB contractor modified the standard canoe tray design for stowage bags to a hard attachment design with tie-down straps to accommodate the Elektron-V liquid unit (134 kg) while Energia developed special Elektron-V caps suitable for use with the canoe's straps. These activities were performed in a quick time frame and late in the flight preparation final stage. Furthermore, the 800A unit attachment locations on the SPACEHAB's aft bulkhead were modified. The special design of these accommodations allowed their use for return cargo.

This flight returned more Russian cargo than any other flight (600.74-kg).

4.3.2.6 STS-86

The SPACEHAB module's loading flexibility allowing the stowage of large amounts of cargo at the launch pad assisted in delivering the most Russian hardware yet aboard this flight (1,948.27 kg).

The design of SPACEHAB's forward and aft bulkheads was specially modified for rigid attachment of nine storage batteries (Units 800A).

The peculiarity of this flight's processing was the fact that a significant part of the Russian logistics was delivered to KSC less than a month prior to launch because of the real-time developments aboard the station related to collision of the Progress cargo vehicle and the Spektr module. This flight carried 17 items of repair hardware (approximately 170 kg) in support of Spektr repair and recovery. A part of this hardware was stowed in the SPACEHAB double module while another part was placed in the ODS stowage bag.

In addition, at L-4 days an agreement was reached to deliver a *Mir* onboard computer (Unit 11M617-1). This item was stowed across two battery top plates on the SPACEHAB aft bulkhead two days prior to launch.

4.3.2.7 STS-89

This flight's primary stowage location was the SPACEHAB double module. Like STS-84 and STS-86 this flight utilized stowage locations in the rear of the module on the center and outer subfloor panels, the aft and the forward bulkheads and port and starboard racks. For example, two portable air pressurization units (APU) were located on the outer subfloor panels while the BKV-3 air conditioning unit was stowed in the canoe attached to the center subfloor panel. These items were secured with straps. The BKV-3 was equipped with a special Energia-developed cover for protection against the effect of the straps. The 800A units were installed in the modified stowage locations on the aft bulkhead. Special fasteners were designed for the SPACEHAB battery top plates to hold soft stowage bags which contained solid waste containers. This freed up additional volume used to stow other hardware. A part of the cargo (e.g., the Salyut-5 central computer) was located in the crew cabin mid-deck in flight bags.

For the first time, hardware was removed and replaced with other hardware during MVAK operations. The full, pressurized APU was removed from SPACEHAB's subfloor and replaced by BKV-3, which is the largest (615 x 625 x 855 mm) and heaviest (82.35 kg) item ever to have been installed at the launch pad.

4.3.2.8 STS-91

The final *Mir*-NASA Orbiter flight (STS-91) utilized a SPACEHAB single module for Russian logistics stowage. Inside the SPACEHAB module, Russian logistics were accommodated in double racks, on the forward and the aft bulkheads. In addition, some of the biotechnology experiment hardware (Biomagnistat, BIOKONT-T, YADRO-BAV, and REKOMB-K) was installed in the mid-deck several hours before launch due to shelf-life limitations.

4.3.3 Conclusion

In conclusion, it must be noted that throughout the *Mir*-Shuttle and the *Mir*-NASA Programs, each flight was used to develop and verify new stowage capabilities for Russian cargo, new attachment designs, to acquire experience in the vertical launch-pad loading of large and heavy equipment and cooperation between U.S. and Russian experts in the course of pre-flight Orbiter processing.

4.4 Principal Stages of Orbiter Processing for Carrying Russian Logistics

The implementation of the *Mir*-Shuttle/*Mir*-NASA Programs has seen both U.S. and Russian experts working together in the processing of nine Orbiter vehicles (STS-71, -74, -76, -79, -81, -84, -86, -89, -91) delivering Russian logistics to the *Mir* station.

4.4.1 Joint Documents

The WG-0/RSC E/NASA/0005 joint requirements document ("Mission Schedules and Cargo Traffic Plan") was developed in support of *Mir*-Shuttle/*Mir*-NASA Program implementation. This document showed the *Mir* station and Russian and U.S. vehicle flight schedules as defined in the *Mir*-Shuttle/*Mir*-NASA Programs. In addition, the 0005 document contained *Mir* traffic data. The appendices to this document showed integrated flight schedules and lists of cargo for delivery to and return from *Mir*.

Furthermore, another requirements document was developed for the *Mir*-NASA Program (WG-0/RSC E/NASA/0006, Catalog of Functional Cargo Transported by the Orbiter under the *Mir*-NASA Program). The data in the document were for use by RSC-E and NASA when planning and executing *Mir*-NASA flights. The document described cargo items for transfer between the Shuttle and the *Mir* orbital facility as well as the relevant requisite documents. This document is an official joint agreement with regard to operations with these cargo items both on the ground and in-flight defining also the hardware required to carry Russian items including interfaces.

It also described the procedures and the equipment required to implement the transfer and the data to be exchanged by RSC-E and NASA to support assessments and decisions relative to these operations. In addition, this document contained data with regard to the environment in the Orbiter's pressurized volume including contingency environmental parameters.

As the data of the flight schedule and Shuttle cargo complement changed for each flight, both documents went through a number of planned updates (L-6 months, L-3 months, L-1 month, preflight, and postflight versions).

As prescribed by the 0005 and 0006 requirements documents which list the cargo items to be transported to *Mir* by the Orbiter, flight-by-flight joint engineering documents were developed under the *Mir*-Shuttle/*Mir*-NASA Programs:

WG-3/RSC E/NASA/3411-1, Delivery and Return of Russian Payloads Aboard STS-71;

WG-3/RSC E/NASA/3413-2, Transportation of Russian Payloads Aboard STS-74;

ICD-SH/RL/M03 (M04-M09), SPACEHAB/Russian Logistics. Interface Control Document [ICD] (for STS-76, -79, -81, -84, -86, -89, -91).

These documents defined all the interfaces between the support structure of the Orbiter's pressurized volumes as well as the Spacelab/SPACEHAB modules and the Russian logistics transported in each of the Orbiter's nine flights depending on the specific cargo stowage location. Furthermore, these documents defined the requirements and the responsibilities of the parties relative to ground operations and payload integration. These joint documents served as the primary reference for Russian logistics operations at the Space Station Processing Facility (SSPF), the SPPF, and when installing part of the cargo at the launch pad at KSC.

All the documents were developed and coordinated prior to each of the nine flights as per the Phase 1 management plan for the joint effort of Russian and U.S. experts.

Following each Shuttle flight, the working group supporting Russian logistics processing for flight prepared a joint technical report. The report reflected all the sequential processing stages and the results of the completed flight.

4.4.2 Preflight Operations

4.4.2.1 Delivery lead times for cargo and hardware items to be installed aboard the Orbiter under the *Mir*-NASA Program were based on the requirements below:

- RSC-E informed NASA 10 to 6 months prior to launch of any request to transport large and heavy cargo (exceeding 80 kg) requiring rigid attachment.
- Large cargo items weighing in excess of 80 kg would be delivered to KSC at 6 to 4 months prior to Orbiter launch.

4.4.2.2 In the course of the *Mir*-NASA Program implementation, there were exceptions to the jointly agreed to requirements and constraints in the over 80 kg cargo category.

In the course of STS-84 processing, 1.5 months prior to launch, the program managers agreed to deliver hardware for the Elektron-V system to repair failed equipment. Considering the fact that one of the Elektron-V units was large (1,328 x 430 x 341 mm) and heavy (design mass of 117 kg) and was supposed to come as a late delivery, a decision was made to simulate its vertical SPACEHAB loading and installation. To support the implementation of this decision, RSC-E shipped a mock-up of the Elektron liquid unit to KSC.

RSC-E, SPACEHAB/Boeing, and KSC experts simulated the unit's vertical loading, modified the framing and the caps, performed mechanical testing and agreed to the flight attachment setup.

The simulation served to verify the basic feasibility of MVAK loading of the flight unit into the Orbiter.

The Elektron-V flight article was delivered at L-1 month. The delivered weight with the end caps of 137.9 kg far exceeded the design mass. This caused the vertical loading of the flight unit to be impractical for reasons of lifting equipment maximum load constraint (up to 123 kg). The unit was installed with the SPACEHAB module horizontal, resulting in a delay to the SPACEHAB rollout from the SPPF for integration with the Orbiter at KSC.

In the course of STS-89 processing, less than 1 month prior to launch, the program managers agreed to deliver an air conditioning unit (BKV-3) to replace failed equipment aboard the station.

BKV-3 was delivered two weeks before the Shuttle launch. The mass of the unit was 82.35 kg.

Spacehab, Inc. made a BKV protective cover and a BKV mockup available for simulation.

BKV was installed in the location of one of the three portable APU located in the canoe in the middle of the subfloor of SPACEHAB's rear section. The operation to replace the pressurized APU with the BKV-3 was performed at the launch pad 5 days before launch with the Orbiter vertical.

Cargoes under 80 kg as well as soft and small articles (clothing, small tools and assemblies) were delivered to KSC at L-3 months to L-1 month.

4.4.2.3 In the course of the *Mir*-NASA Program implementation there were exceptions to the jointly agreed to requirements and constraints in the under 80 kg cargo category.

Decisions with regard to cargo delivery by the Orbiter (with late shipment to KSC) were made by the Phase 1 program management under extraordinary circumstances created by the real-time developments aboard *Mir* or other reasons of importance to the *Mir*-Shuttle/*Mir*-NASA Programs.

In the course of STS-71 processing, the following items were delivered less than a month prior to launch: sealing kits, cutting tool (EVA) and additional onboard station crew procedures (*Mir*-19). All of the above items were stowed several days before launch.

In the course of STS-74 processing, RSC-E representatives delivered a set of adapters for U.S.-made CO_2 absorbers at L-3 days. Additionally, the U.S. manufactured two kits of adapters of its own to ensure that the U.S. CO_2 absorbers would be used aboard *Mir* when delivered by the Orbiter. The U.S. and Russian adapter kits were installed in the mid-deck immediately prior to launch.

In the course of STS-76 processing, the Analysis-3 kit with hose was delivered at L-2 weeks for urgent delivery to *Mir* to support atmospheric station monitoring following Priroda docking. These items were stowed in mid-deck lockers.

In the course of STS-79 processing, two vacuum valve units (BVK), nitrogen purge unit (BPA), and two Penguin-3 suits were delivered at L-2 weeks for urgent delivery to *Mir*. BVK were delivered to *Mir* to replace failed valves while BPA was designed to support nominal atmosphere aboard the station.

In the course of STS-84 processing, the ША294 transmitter was submitted less than a month prior to launch for urgent delivery to the station to replace failed equipment. At L-3 days environmental monitoring hardware was delivered (hardware kits for Elektron-V, Vozdukh, TCS) as well as medical kits.

In the course of STS-86 processing, 17 items of repair equipment (total mass approximately 170 kg) were delivered at L-2 weeks in support of Spektr repair and recovery operations. Simulations were run of repair hardware integration in SPACEHAB and ODS flight bags. Three items of a hardware five-item set were stowed in the ODS.

At L-3 days, the onboard computer (Device 11M617) and a VHS tape containing Spektr repair instructions were delivered for integration aboard the Orbiter.

In the course of STS-89 processing, a compressor unit (BKV) and a central exchange module (ЦМО) were delivered at L-2 weeks for urgent delivery to the *Mir* station for failed equipment repair.

At L-5 days, an onboard computer (Device 11M617) was handed over to replenish the onboard store of spares.

In the course of STS-91 processing, biological experiment hardware was delivered several days prior to launch as well as a kit containing 3.5" diskettes for the computer system. All the hardware was installed in the Orbiter mid-deck.

Limited-life cargo (food and certain hygiene items) were delivered to KSC at L-1 month. At this time, Russian cargo was turned over to KSC personnel for integration. This did not include a time allowance for special operations in the course of the handover. The requirement for special operations, such as checkout, testing, or assembly dictated an earlier delivery date and was specified on a case-by-case basis.

4.4.2.4 Russian Hardware Requiring Special Processing Prior to Shuttle Integration (With the Exception of the Russian Docking Compartment Not Considered for the Purposes of This List):

- Unit Г16М (gyrodyne): required checkout, testing, and assembly to the fastening ring (adapter). (STS-76, -79, -81, -84, -86, -89, -91 processing)

- Units Г15М, Г16-5: required checkout and testing. (STS-84, -86, -89, -91. During STS-86 processing, one Unit Г16-5 failed to be certified for flight following testing)

- Water containers (EDVs): required assembly of six EDV housings into a single set to save volume on the Orbiter. (STS-76, -79, -81, -84, -86, -89, -91 processing)

- Incubator 1M Control and Monitoring Module: required water servicing and leak check (STS-76 processing).

- Nitrogen purge unit: required checkout, testing, and nitrogen pressure charging (STS-79 processing).

- ALIS Adapter: required interface compatibility checkout to support ALIS hardware safe return (STS-81 processing).

- Elektron-V liquid unit: required checkout, installation of end caps, and SPACEHAB integration simulation (STS-84 processing).

- Portable APU: required checkout, testing, and air pressure charging (STS-86, -89, -91; prior to STS-91 the APU was charged with nitrogen rather than air).

- Spektr repair equipment: required checkout, partial assembly, and installation simulation (STS-86 processing).

- Air conditioning unit (BKV-3): required checkout, installation of protective cover, and installation simulation (STS-89 processing).

- Compressor unit (BKV-3): required checkout (STS-89 processing).

- Biotechnology hardware (Biomagnistat, BIOKONT-T, YADRO-BAV, and REKOMB-K): required checkout, diagnostic testing (STS-91 processing).

The above items underwent ground processing based on special procedures. All the other equipment underwent such operations as are prescribed by the 0006 document as well as simulation of flight kits in the SPACEHAB module and the mid-deck.

The transport containers with RSC-E hardware for a specific Shuttle flight were delivered under a special customs clearance by a freight carrier acting for RSC-E. Following delivery into the U.S., the containers were brought to KSC, the Space Station Processing Facility (SSPF, or the SPPF). NASA provided storage and assembly space for the Russian cargo as specified in requirements listed in joint documents until such cargo was formally handed over (inspected) and integrated on the Orbiter. All the Russian cargo was stored in their transportation containers.

RSC-E deliveries included:

- a set of Russian logistics for a specific Orbiter launch;

- a set of auxiliary hardware for a specific Orbiter launch to attach the Russian logistics on the Shuttle;

- a set of ground support equipment designed for Russian cargo checkout, testing, and simulation;

- containers for Russian primary and auxiliary equipment carriage;

- containers for ground support equipment.

Ground hardware including handling tools, was delivered by RSC-E to KSC at the same time as the flight hardware.

NASA provided the following equipment:

- a set of ground support equipment designed for Russian cargo checkout, testing, and simulation;

- ground support equipment for Russian cargo integration and de-integration;

- support structure for Russian cargo in the Orbiter crew compartment;

- support structure for Russian cargo in the SPACEHAB and the Spacelab modules;

- Orbiter flight cargo stowage facilities (containers, stowage bags, etc.).

In the course of preflight processing, NASA photographed the hardware being handed over as well as the assembly of the U.S.-Russian interfaces. Copies of photographic data were made available to RSC-E.

NASA and RSC-E representatives performed visual inspection, measurement and weighing of cargo immediately after each separate portion of the cargo was removed from the transportation container. This verification served to confirm that the Russian cargo items had not been damaged in transit and are in compliance with the data listed in the joint working documents. Following visual inspection, NASA representatives filled out the transfer-of-responsibility form for the Russian cargo and took over the responsibility for each individual item of hardware.

The installation and stowage of Russian logistics aboard the Orbiter was performed by NASA experts based on the Shuttle schedule and the NASA documents respecting the integration and stowage of Russian logistics taking account of the requirements and constraints levied by RSC-E. SPACEHAB/Boeing personnel performed the installation and stowage of Russian cargo in the SPACEHAB module. NASA supplied all the fasteners, gaskets, and attachment and stowage tools required to integrate Russian logistics on the Orbiter. NASA provided detailed documentation with regard to Russian cargo integration to RSC-E representatives prior to these operations.

Throughout the *Mir*-NASA Program, RSC-E representatives received maximum access to monitoring Russian cargo processing, transportation, and final Orbiter stowage operations.

4.4.3 Joint Shuttle-*Mir* Mission Operations

As prescribed by distribution of responsibility agreements, the U.S. side was responsible for the special handling devices and de-integration tools in support of the removal of the Russian logistics from their stowage locations on the Orbiter as well as for their transfer to the *Mir* interface. The Russian side was responsible for the special handling devices and de-integration tools in support of the removal of the Russian logistics from their stowage locations on *Mir* as well as for their transfer to the Orbiter interface.

Mir-NASA program management was responsible for the transfer of hardware shown in jointly agreed to lists. MCC-H and MCC-M supplied NASA Phase 1 management with data to develop the transfer plan, including all measures and documents with regard to the transfer of the hardware shown in jointly agreed-to lists. The U.S. side was responsible for the cargo and operations aboard the Shuttle vehicle. The Russian side was responsible for the cargo on operations aboard the *Mir* station. Shuttle astronauts and *Mir* cosmonauts performed cargo transfer.

The accessories and tools for in-flight Russian cargo operations aboard *Mir* (including nominal installation) were provided by RSC-E. NASA supplied fasteners as well as any tools required to secure Russian cargo aboard the Orbiter.

NASA developed mechanical interfaces between Russian cargo and auxiliary hardware and the Orbiter structure taking into account the RSC-E requirements and recommendations for every specific Shuttle flight to *Mir*. The mechanical interfaces were defined in joint working documents 3411, 3413, or ICD.

A specially trained cosmonaut was responsible for the operations and procedures related to the transfer of Russian cargo from the *Mir* station to the vicinity of the Shuttle/*Mir* interface. Similarly, a specially trained U.S. astronaut was responsible for all operations related to the movement of this cargo from the above vicinity into the Orbiter and its stowage. NASA developed procedures for the transfer of Russian cargo from the Shuttle/*Mir* interface into the Shuttle. NASA also developed procedures for the stowage of the above cargo. Similarly, RSC-E developed all the procedures for the removal of the Russian cargo from the *Mir* station for transfer to the Orbiter.

The Orbiter crew recorded all cargo transferred to and from *Mir* in a log. This log contained information from the WG-0/RSC E/NASA/0005 joint document with regard to the cargo traffic plan. Also, data were available with respect to the location of the hardware to be transferred both on the Shuttle and *Mir*. One of the crew members made entries in the log showing the date and time of hardware transfer. At the end of each flight day, the Shuttle and *Mir* crews reported to the ground on work accomplished. Copies of the daily transfer log were sent to MCC-H and MCC-M. Transfer items were added to and updated as coordinated by the two Mission Control Centers.

An exchange of information on the preflight traffic planning and participation by working group membership in mission control operations proved a significant help to both the Mission Control Centers in monitoring and completing cargo transfer operations between the *Mir* station and the Orbiter vehicle during each joint flight.

4.4.4 Postflight Operations

Postflight operations related to Russian logistics were performed at KSC. If the Orbiter vehicle landed in another location (STS-76 landed in California), Russian cargo remained aboard the Shuttle until its delivery to KSC.

NASA developed a procedure for the removal of Russian cargo from the Shuttle. RSC-E, in turn, developed special instructions and constraints to these operations. NASA was responsible for complying with these requirements. RSC-E informed NASA one month prior to Orbiter launch of those return items that needed to be de-integrated from the vehicle earlier than the time specified in the joint agreements.

NASA provided the ground-support equipment required at KSC to de-integrate Russian logistics from the Shuttle. RSC-E supplied handling devices, as needed, for the stowage of the cargo in question in transportation containers. In the course of handling, measures were taken to prevent falls, impacts, or other incidents leading to damage.

RSC-E provided transportation containers for the return of Russian cargo to Russia following flight completion. RSC-E took delivery of its hardware at KSC. The RSC-E carrier arranged for the transportation of Russian cargo to the airport of departure for Russia. NASA informed the RSC-E carrier of cargo readiness for transportation. Transportation containers designed to carry Russian return cargo with the auxiliary hardware were shipped to KSC in advance.

NASA was responsible for the removal of Russian cargo from the Orbiter following its landing taking into account the requirements and constraints coordinated with RSC-E. NASA and RSC-E took an inventory of the return Russian cargo as required by the procedure for the official transfer of responsibility for the cargo to RSC-E. Any discrepancies discovered in the course of inventory taking were recorded. Any problems arising in connection with the inventory taken by NASA were resolved in conjunction with RSC-E and joint decisions were made prior to the transfer of responsibility.

The sequence of operations for the shipment of Russian cargo from KSC to RSC-E following a Shuttle landing is shown below.

1. NASA completed Shuttle off-loading and payload inventory based on the down cargo list.

Item 1 + 3 weeks

2. NASA and RSC-E prepared a transfer of responsibility document whereupon NASA transferred the payload to RSC-E representatives.

Item 1 + 2 days (Landing + 3 weeks + 2 days)

3. In the presence of NASA personnel, RSC-E packed all the payloads into containers using its own packaging material and NASA-provided material as required.

Item 2 + 4 days (Landing + 3 weeks + 2 days + 4 days)

4. RSC-E arranged for the insurance and air transportation of payload containers and supplied NASA with the information appropriate for the processing of customs documents.

5. Simultaneously with activities in Paragraph 3, NASA prepared paperwork for customs clearance.

6. NASA notified the RSC-E carrier responsible for the delivery of payload containers from KSC to the airport of departure that the cargo was ready to ship. The carrier delivered the transportation containers with payloads from KSC into customs, cleared cargo through customs, and delivered them to the airport for shipment to Russia (RSC-E).

Item 3 + 3 days (Landing + 3 weeks + 2 days + 4 days + 3 days)

Documentation required to carry Russian cargo to RSC-E was issued by NASA. NASA assured completion of all customs formalities in the U.S. RSA/RSC-E assured completion of all customs formalities in Russia.

4.5 Parties' Primary Accomplishments Under *Mir*-Shuttle/*Mir*-NASA Programs

1. The coordinated effort by the Joint Manifest Working Group under time critical conditions to the stowage of late items for delivery aboard the Orbiter.

2. A completely up-to-date set of engineering documents on cargo traffic (i.e. Document 0005, Document 0006, ICD).

3. The accommodation of large hardware items in the Shuttle mid-deck and SPACEHAB module: Elektron-V for STS-84 and Spektr repair hardware for STS-86, etc.

4. The expedited delivery of critical hardware to *Mir*.

5. Utilization of the U.S. cargo traffic database to generate joint documents.

6. The coordination and implementation of a very effective Orbiter stowage schedule for all limited-life Russian logistics.

7. The rapid (2 days) and efficient transfer of 4.5 tons of cargo to and from *Mir* using *Mir* and STS-86 crew.

8. The use by *Mir* of potable and technical water produced from the water generated by the Orbiter's power supply system.

9. The return of vehicle components (KURS, TORU, and Elektron-V) and gyrodynes by the Orbiter from *Mir* for reuse.

10. The accomplishment of the planned cargo traffic supply by Shuttle to *Mir* was achieved ahead of time (by the 8th mission).

11. The delivery of the large DM by the Orbiter and its docking with the *Mir* station.

12. Successful transfer of the electronic database during flight allowing real-time manifest updates by the Russian side.

13. In the course of the transfer of responsibility for the Russian logistics, SPACEHAB/Boeing and Russian experts utilized an efficient method allowing rapid return of cargo to Russia and delivery of hardware for flight. Making operations space available to the customer at the SPPF furthered the success of this process.

14. The familiarization with Russian cargo items by U.S. experts and the familiarization of Russian experts with the SPACEHAB module and Shuttle mid-deck stowage capability assisted in successful cargo traffic planning.

15. The cooperation on the part of SPACEHAB in developing and modifying interface hardware (such as modifications to the canoe, battery adapter plates, etc.), especially immediately prior to launch ensured successful accommodation of large, late manifested items.

16. The successful operations utilizing the module vertical access kit (MVAK) to load late-manifested Russian items.

17. For timely delivery of Russian cargo, the SPACEHAB Projects Group was required to obtain detailed knowledge of the cargo customs clearance and international transportation regulations.

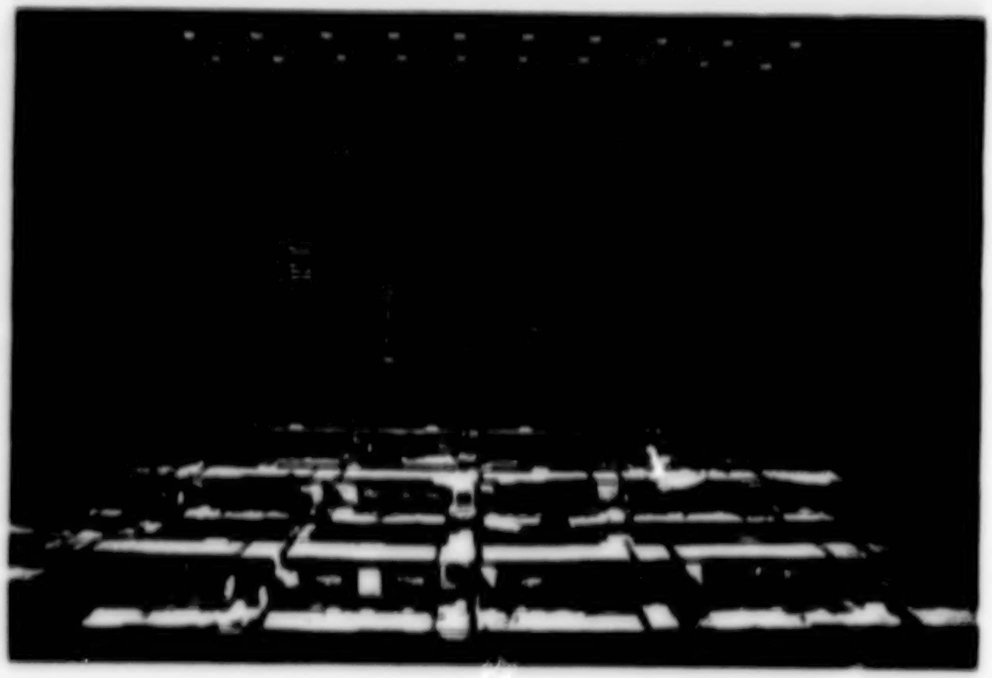
18. To comply with Russian cargo requirements (e.g., with regard to the portable APUs, regular carriage of biotechnology hardware falling under the heading of hazardous cargo) PGOC and flight crew equipment lab personnel worked in close contact with the Joint Manifest and Schedules Working Group.

19. The information contained in the Russian Logistics Catalog (Document 0006) allowed experts to perform expedited assessments of Russian logistics accommodation and served as basis for the development of requirements levied against the complement, the dimensions, mass and ground handling operations.

20. Continuity of the Joint Manifest Schedules and Working Group membership throughout the *Mir*-NASA Program (i. e. use of the same experts for all the flights) fostered a working relationship and a free exchange of information allowing close contact and a high degree of trust and cooperation among group members. It allowed for timely solution of seemingly insurmountable problems and excluded unproductive use of work time.

21. During STS-89, for the first time, replacement of large Russian cargo was performed in SPACEHAB at the launch pad (an APU was replaced with the BKV-3 air conditioner) with the BKV-3 mass of 82.35 kg, the heaviest ever.

STS-79 astronaut Tom Akers performs an inventory of items to be transferred to the *Mir*



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Section 5 - Joint Shuttle-*Mir* Operations

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5.1 Mission Control and Real-Time Operations During Shuttle Docking Flights

5.1.1 Introduction

The Phase 1 Program included a total of 10 joint Shuttle-*Mir* missions. The first of these, STS-63, was designed only as a rendezvous demonstration mission, since the Shuttle carried no docking mechanism. This flight provided a validation of the rendezvous technique and MCC to MCC interactions that would be required on all subsequent missions. All nine remaining missions included successful dockings, transfers of cargo and consumables, exchanges of both U.S. and Russian *Mir* crews, and the performance of joint docked experiments.

The Shuttle and the *Mir* were originally developed independently, for fundamentally different purposes, and were not inherently compatible vehicles. Numerous dissimilarities required both engineering and operational solutions to facilitate joint operation of the docked vehicles. The processes developed to achieve these solutions, the procedures and techniques used to execute them, and the knowledge gained from nominal flight and unexpected events are all the primary basis for the development of joint operational principles for future programs such as the International Space Station (ISS).

5.1.2 Implementation of Joint Operations

The development of a joint operations process was divided into numerous functional areas or subgroups. Prior to each joint flight, each discipline's top-level agreements for the conduct of planned operations were documented in Joint Agreements, which were the source of the detailed operational plans and procedures for flight. A document control process for making changes to these documents was developed, so that both parties could review and agree to the proposed changes. Although this process was somewhat cumbersome and could be refined for future programs, the concept of using configuration-controlled documents is valid and contributed to the success of the joint program.

Real-time operations for the Shuttle-*Mir* missions were conducted with the agreement that neither vehicle and neither MCC was in charge of the joint operation. The MCC-M controlled and had authority for the *Mir*, and MCC-H was responsible for the Shuttle. Similarly, the Shuttle commander was responsible for the Shuttle and crew, and the *Mir* commander was likewise responsible for his vehicle and crew. This arrangement formed the basis of a need for mutual agreement on every aspect of joint operations. One of the primary tools for these agreements was the use of Joint Flight Rules. Developed before each mission, these written rules documented both planned operations as well as responses to off-nominal situations. The rules minimized the need for real-time decisions, and ensured that all impacts of each course of action had been reviewed and agreed by both sides for operational adequacy.

Execution of the joint missions required coordination between two control centers thousands of miles away from each other, in different time zones, and with different native languages. Communications links, processes and procedures were developed to exchange information between the control teams, coordinate decisions, and accommodate changes of plan. In addition to development of these joint control center capabilities, groups of consultants were exchanged during the mission to facilitate technical discussions between the control centers, and to observe and learn how the other team performed their tasks.

The detailed planning and control of the joint missions was performed through joint consensus at the individual discipline level; for example, the orientation requirements were agreed to by the respective attitude experts, procedural issues were worked out by the individual procedure specialists, and so on. Addressing the issues at this level resulted in mutually acceptable recommendations to the Flight Directors and mission managers, and was a very efficient method of resolving technical issues.

5.1.3 Joint Operations Accomplishments

The planning and execution of these joint missions encompassed many significant accomplishments. There were numerous challenges resulting from the technical complexity of the task as well as the practical considerations of technical and language differences. Among the most significant are:

Docking of very dissimilar vehicles — The operational techniques for final approach and docking of the Shuttle to the *Mir* orbital complex were developed and gradually improved over the duration of the program. The *Mir* complex continued to change throughout the program with the relocation and addition of modules and relocation of solar arrays. Issues of plume loads, contact loads, and vehicle dynamics required continual reassessment to account for these changes. During the early portion of the program the Shuttle technique was changed from approaching from the velocity vector ("V-bar approach") to approaching from below ("R-bar approach") in order to help reduce plume-loading concerns. Throughout the joint program the dockings were consistently within the required contact conditions.

Technical Operation of the Docked Complex — Mutually compatible operation of the Shuttle-*Mir* complex required extensive work in the areas of attitude control, thermal and power management, and atmosphere maintenance. The primary strategy for attitude and atmosphere control was to allow a single vehicle to control, thus avoiding interactions between the two vehicles' systems. Refinement of the Shuttle digital autopilot control parameters and hardware additions to the Shuttle environmental control system were required to accomplish these changes. The technique of replenishing the *Mir* atmosphere from excess Shuttle consumables was a byproduct of this work. Management of the attitude was complicated due to the conflicting requirements of the two vehicles. Management of the attitude was complicated due to the conflicting requirements of the two vehicles. Extensive efforts were necessary to balance power generation for *Mir*, *Mir* and Shuttle thermal considerations, communications antenna blockage, and attitude control propellant usage.

Mission Control Operations — One of the greatest challenges of the joint operations was the coordination of control between the two mission control centers. The development of strong working relationships between the two control teams required practice through simulations and the development of clear, unambiguous communications channels and methods. Special console positions (RIO and PRP) were created to assist with this interface function. Procedures were developed for information exchange between the control centers, specifying reporting points, and making decisions. In addition, the use of the Consultant Groups provided a capability for detailed face-to-face technical discussions, when required. All of this work was performed in different languages, requiring the use of interpreters. The successful accomplishment of the entire sequence of missions serves as testimony to the technical abilities of both sides, given the practical difficulties. The mutual trust and respect for technical ability developed through the joint meetings and pre-mission work were crucial to this working relationship.

5.1.4 Joint Operations Lessons Learned

Dual Language Procedures — Although each Shuttle crew had at least some familiarity with the Russian language, and the Russian crews knew some English, it was not possible within the scope of the Phase 1 Program to converge to a single-language operation. Yet in the interest of safety and effective operation, it was crucial that both sides have a clear understanding of all procedures and plans. As a result, a method was developed to present all detailed joint procedures in both languages. Identical steps in each language were printed on facing pages of checklists. Printing techniques were used to distinguish which steps were to be performed by each side. Because it was crucial that both MCCs fully understand the flight rules, they too were printed in both languages on facing pages. Crew timelines were presented in both English and Russian as well.

In the future, when more than two languages are involved, as with the ISS, convergence to a single language of operation would be preferable where the time is available to gain language proficiency for all parties. However, it is still crucial that some time-critical and safety-critical procedures be absolutely clear and easily understood in an emergency, so some minimal amount of multilanguage procedures may be required.

Crew Operations — The efficient utilization of the combined Shuttle and *Mir* crews required clear planning and coordination. Conduct of the transfer operations for cargo, performance of experiments during docked operations, handover time for the long-duration crew change, and routine operation of both vehicles' systems created complex demands on crew time and available volume. Over the length of the Program the planning technique evolved significantly, resulting in a mixture of tightly constrained crew events and loosely scheduled crew time to complete unconstrained activities. The daily exchange of information between the MCC teams allowed planners to monitor the completion of tasks. Time was scheduled for both crews to meet and review the daily plans in order to improve coordination between the two crews.

Sleep Cycle Management — The *Mir* crews were accustomed to a standard-length 24-hour day on a repeating schedule, synchronized with Decreed Moscow Time (DMT). Shuttle crews, however, have a variable crew workday length in order to adjust the crew wakeup times to support launch and entry schedules. Due to orbital mechanics effects, the sleep/awake periods for the two crews rarely coincide. However, efficient crew worktime requires that some minimum joint workday must be achieved and compromises were required from both crews in order to align the workdays. Through the Phase 1 experience it was determined that the minimum joint workday for the crews should be at least 8 hours of joint worktime in order to accomplish the transfer of the full cargo and perform the other assigned tasks. This required shifting the sleep period of the station and Shuttle crews each by as much as 4 hours.

5.1.5 Applications to ISS

While many of the operational techniques and specific procedures developed in the course of the Shuttle-*Mir* program were specific to the *Mir*-Shuttle configuration, many general principles can be applied to future joint operations such as ISS.

Joint Control Team Structure — For Phase 2, there will be both U.S. and Russian control teams for the ISS vehicle. Unlike the Shuttle-*Mir* program structure, the ISS will be operated as a single combined vehicle, with the Russians responsible for executing Russian segment operations and the U.S. responsible for the U.S. segment. However, the U.S. will maintain responsibility for the overall conduct of the ISS operation. Although one control center will have primary overall control responsibility at any given time, the principle of joint coordination at the discipline level and agreement between Flight Directors will still be the primary operational technique, an approach which was developed during Phase 1. The use of consultant groups will be continued in the ISS team structure.

Structure of Joint Documentation:

The use of documented Flight Rules and MCC procedures will continue as standard operational practice. The system of agreeing to and introducing changes to joint documents, developed during Phase 1 missions, may be fully applied to the ISS.

Acceptance of Joint Decisions:

The interaction of the MCC's and their Flight Directors during nominal flight and during emergency situations was adjusted and assured the success of the 9 missions. The exchange of flight documentation and real-time procedures for making decisions including: oral discussions of the problems, questions via fax, and Flight Director briefings to provide the partner with exhaustive data concerning the problems that arise will apply, in general, to the ISS.

Joint Planning:

Joint planning and agreeing on the joint plans during Phase 1 was also refined and in general may be used for the ISS. It would be useful to expand the use of digital communication links and equipment for real-time exchange of plan variations to accelerate their concurrence.

The use of the partner's flight and ground segments:

The partner's flight segment during Phase 1 was used fairly widely (exchange of atmosphere, vector states, step-by-step attitude control, and the use of the partner's ground stations and communications links). It follows that this practice will be continued on the ISS and further advanced in the direction of increasing these types of services.

And, finally, in the area of engineering accomplishments, the most important accomplishment of Phase 1 would be the friendly, creative atmosphere that developed among the specialists of our countries during the Phase 1 joint operations.

5.2 Operations During the Long-Duration Missions

5.2.1 Executive Summary of the Joint *Mir* Operations and Integration Working Group (MOIWG/WG-6)

The Joint *Mir* Operations and Integration Working Group (MOIWG/WG-6), was established in the Spring of 1995 as a part of the Phase 1 Program, and was responsible for the implementation of the joint NASA/*Mir* Research Program on board the Shuttle and *Mir*-Orbiting Station (OS). Given this, the Joint MOIWG was tasked with the responsibility of developing, defining, and executing the processes of integration, mission preparation, and operation of joint research on the Shuttle and *Mir*-OS. Through the use of the jointly agreed upon Integrated Payload Requirements Documents (IPRDs), research program requirements were baselined and implemented through various joint working group documents and protocols. This implementation included, but was not limited to, flight crew and ground controller training, integration of payload and medical hardware, operation preparation and execution, as well as real-time mission support for the flight crew on-orbit. On the U.S. side, the MOIWG functions were divided into five functional groups: Analytical Integration, Mission Management, Operations, Training, and Integration Integrated Product Teams (IPTs). Each of these areas interfaced directly with the payload disciplines and other Phase 1 Program Working Groups to further define requirements and develop an implementation plan to execute the program requirements. The MOIWG also interfaced with multiple Russian organizations such as the Institute of Biomedical Problems (IBMP), RSC-Energia (RSC-E), TsNIMASH, and the Gagarin Cosmonaut Training Center (GCTC) to complete these joint activities.

The accomplishments from the Phase 1 Program included not only the scientific return, but also the knowledge gained on how to plan for and conduct long-term operations aboard a space station. The past histories of both the U.S. and Russia in their respective programs — Mercury, Gemini, Apollo, Skylab, and Space Shuttle; Vostok, Voskhod, Soyuz, Salyut, and Mir — brought different cultures with respect to planning and operations for spaceflight activities to the Phase 1 Program. By working together, the two sides learned to employ the best practices of each program to come to terms with the constant flow of technical, operational, and political issues that are part of the dynamic nature of a permanently manned space station environment.

The following sections briefly describe the structure, processes, joint accomplishments, and recommendations from each of the components of the MOIWG.

5.2.2 Analytical Integration Team (AIT)

5.2.2.1 Overview

The MOIWG was responsible for ensuring payload test and integration, preparation of required test and integration documentation, flight crew training and supporting documentation, actual integration of payload systems on board, execution of experiments and investigation in real time, and processing and distributing pre- and postflight data as required.

The MOIWG AIT served as the primary coordinating interface for payload requirements, development, delivery, schedule tracking, and issue resolution for the MOIWG. It served as the primary responsible MOIWG entity for management and coordination of payload implementation across the IPTs, the NASA/*Mir* Working Groups, and other NASA and Russian organizations. The relationship between the joint working groups for the purposes of the implementation of the research program was governed by US/R-001.

5.2.2.2 Structure and Processes

NASA was responsible for management of the MOIWG using a programmatic structure across all the Increments within the five major areas: AIT, Mission Management, Operations, Training, and Integration. The use of consistent processes and systems and the implementation of critical lessons learned from previous missions were key to the success of the MOIWG. The prime support team for the MOIWG was also organized along these functional lines, and dedicated increment teams followed each mission from requirements definition and development through postflight analysis and reporting.

The primary document describing the scope of work for each flight increment was the IPRD, as developed by the Mission Science Working Group (MSWG/WG-4).

The MOIWG worked most closely with the MSWG, and the two groups conducted quarterly meetings and reviews jointly with their Russian counterparts, who served as Russian interfaces to WG-4 and WG-6. Due to the dynamic nature of a space station environment, these joint meetings were invaluable since they provided the opportunity for direct contact between the U.S. and Russian science communities as well as the personnel tasked with implementing requirements. In addition, critical issues were brought forward to the program through weekly NASA Phase 1 Program meetings and telecons and through periodic Phase 1 Team 0 meetings.

5.2.2.3 Joint Accomplishments

Given the scope of the U.S. Research Program, Russian experts were not involved in establishing experiment objectives, the analyses of experiment results, or the evaluation of experiments, except with regards to the assessment of *Mir*-OS parameters, or in those cases where Russian investigators were directly involved as Co-Investigators.

During the program development and implementation stages, both sides worked together in the spirit of mutual understanding without resorting to undue formality, thereby promoting overall activity success.

A continually improved understanding of the launch and return capabilities and processing schedules of each side's vehicles allowed the program to supply or return critical items based on events that occurred on the *Mir*-OS.

This understanding enabled each side to reevaluate and to replan the scientific program based on the dynamic nature of a space station environment.

5.2.2.4 Joint Lessons Learned/Future Applications

Establishment of working forums to address all issues associated with integration and operation of payload systems on partner elements, especially in the situations of differing module and element designs and accommodations.

Establishment of working forums with decision-making authority and responsibility to implement and execute positions and solutions.

5.2.3 Mission Management IPT

5.2.3.1 Overview

The MOIWG Mission Management IPT was assigned the task of managing the NASA/*Mir* mid-deck science and transfer activities. Some of the primary activities included training the crew members on the STS (Space Transportation System) mid-deck science in-flight operations and/or transfers, assessing ground and flight safety hazards, replenishing consumables, supplying new hardware, returning samples and experiment hardware, providing pre- and postflight ground operations, and leading the destow process at the landing site.

5.2.3.2 Structure

Each of the Payload Element Developers (PEDs) reported to the MOIWG Mission Managers regarding mid-deck payloads under their responsibility, and concentrated on the transportation of the science experiments to/from the *Mir*-OS utilizing the STS.

The Mission Management function entailed many roles and responsibilities ranging from maintaining a manifest of science payloads, real-time operations during the missions and coordinating the postflight activities after landing (destow and ground operations). In addition, the MOIWG Mission Manager served as the MOIWG representative to the Phase 1 IPT in an effort to maintain strong communications.

In addition, the Mission Management Team worked closely with the Spacehab Team to integrate flight hardware manifested in the Spacehab module.

5.2.3.3 Processes

New inputs or changes from the PEDs (in-flight operations and/or hardware changes) were reviewed by the MOIWG Configuration Control Board (CCB) and approved manifest changes were submitted to the Phase 1 Program Requirements Control Board (PRCB). The Mission Management team worked within the MOIWG and with the MSWG to identify the hardware that would be required to support the selected experiments. The final manifest and subsequent changes were then used by the MOIWG Mission Manager to generate the appropriate documentation.

The Mid-deck Payload Requirements Document (MPRD), JSC-27898, defined the PEDs' requirements for mid-deck science and technology payload elements. All STS phases of the ground integration and de-integration, crew training, and flight and ground operations were included in this document.

In addition, the safety team developed the integrated flight and ground safety packages for the mid-deck payloads and compiled the Material Safety Data Sheets (MSDS), Process Waste Questionnaire (PWQ), and Hazardous Material Summary Table (HMST) inputs.

The Mission Management IPT controlled the science hardware ascent/descent manifest using the Phase 1 Requirements Document (P1RD) and provided inputs to Shuttle documentation. Mission Management repeatedly updated and cross-checked the real-time manifest against the official list of hardware items in the IPRD, the *Mir* manifest document (US/R-004), and the Phase 1 Requirements Document in order to maintain hardware configuration control. Updates generated from MOIWG CCB Directives were reflected in the P1RD and in Shuttle documentation. Timeline issues were primary considerations in development of the Shuttle manifest as well. Ensuring that the timeline matched the late changes in science requirements was an important Mission Management Office (MMO) responsibility.

5.2.3.4 Joint Accomplishments

During the course of the Phase 1 Program, MOIWG Mission Management developed plans and procedures, including the following:

1. Mid-deck Science Familiarization - A mid-deck science familiarization was presented to the assigned flight crew and Mission Operations Directorate (MOD) flight controllers. This provided the crew a general overview of the mid-deck payloads, any payload constraints, cold stowage (requirements, units flying, contents, general activities involved), training schedule and training activities.

2. Cold Stowage Plan - Due to a well-established plan, carefully executed operations and thorough crew-training, frozen and refrigerated samples were transferred between the Shuttle and the *Mir* on each of the Shuttle/*Mir* flights without any loss of samples.

3. Destow Plan/Ground Operations Plan - A destow process was established that allowed for receipt, inventory and distribution of all Phase 1 hardware in a timely and systematic manner. This provided Phase 1 with a record of what was returned and accountability for that hardware.

4. MMO Manifest - The MMO manifest provided the required detail for MMO to integrate the ascent and descent hardware as well as to provide inputs to the PIRD.

5.2.3.5 Joint Lessons Learned

The following lessons were learned by the Mission Management IPT during their involvement in the Shuttle/*Mir* missions, and would be applicable for ISS.

1. Establish a streamlined configuration control system for processing late changes. Set up a process that brings together key personnel from all required elements to evaluate and disposition all proposed changes subsequent to a freeze point at L-2 months.

2. Formalize preflight coordination between the Shuttle Mission Management, Program Office, MOD, PEDs and *Mir* Long-Duration Integration and Operations IPT members to specifically discuss transfer and operational issues.

3. Hardware drawing names, label names, and part numbers should be included on hardware lists. Common names should be avoided in any official documentation. Developing a separate drawing for hardware labels may reduce drawing changes if the crew has label name modifications. Revision of the JSC Drawing Control

Manual to specify the proper procedures for handling the various nomenclature issues would help. Inclusion of part numbers along with names in procedures and other documentation can eliminate potential confusion.

4. Use the documentation plan as a model for future ground destow operations. Hardware would be delivered to a central location for dispositioning and inventory control. The requirements would be documented in one universally recognized destow document. Alternatively, require the crew to pack all early destow and nominal destow items in separate bags (requires more space and crew coordination on-orbit). The destow plan established is a good template for future programs to build on.

5. Some dedicated facility with adequate processing and laboratory space needs to be identified or constructed at Dryden Flight Research Center for ISS use. The potential loss of long-duration science would far exceed the cost of an adequate facility.

6. Set aside an area onboard station for stowage of common-use supplies such as ziploc bags, Velcro, pens, and batteries. At a specified time prior to the next Shuttle launch, have a crew member inventory the supplies on hand. On the ground, have a catalog of core pre-approved supplies that the Flight Equipment Processing Contract maintains to replenish those supplies. Remove these items from the standard manifesting process. Under the present system, it takes almost as much manpower to manifest a ziploc bag as it does to manifest a payload.

7. Provide an electronic still camera (ESC) to photograph all powered hardware after installation or for any other activities that require detailed configuration knowledge by ground specialists involved with the crew in inspections, troubleshooting, or visual science observations.

5.2.4 Research Program Training IPT

5.2.4.1 Executive Summary

Crew training for the NASA *Mir* Program was an essential component of the success of the research program. Close coordination with the Crew Exchange and Training Working Group (WG-5) was required of the effective planning and implementation of the payload training program. The quality of the crew training was dependent on the constraints of crew schedules and manifests, launch dates, trainer and hardware availability, supporting operational documentation, level of procedure maturity, and programmatic changes. The planning and implementation of crew training for NASA/*Mir* required careful analysis of training requirements, taking into consideration crew background and previous training, as well as science and operational requirements. This was complicated by the use of different launch vehicles for astronauts and cosmonauts. Due to limited crew time, particularly in the U.S., efficient and optimal training was essential. Eliminating redundant requirements and streamlining training session content and methods provided the most efficient training possible. In addition, the IPT coordinated training programs to provide certified ground controllers to operate the Spaceflight Control Center – Kaliningrad (TsUP) and Payload Operations Support Area (POSA).

5.2.4.2 Structure and Processes

The structure of the Training IPT was determined by the requirement for a core group of U.S. and Russian specialists to support payload training across the breadth of the program. This group worked closely in coordinating the necessary support from experiment investigators and developers in the execution of flight crew and ground controller training. With this in mind, U.S. Training IPT personnel were stationed both at the NASA Johnson Space Center (JSC) and in Russia at GCTC. Moreover, this group was responsible for the completion of ground controller training, both in the U.S. and Russia.

Analysis and definition of payload training requirements was based on a thorough review and assessment of science and operations requirements as defined in the IPRD. While the 100 series documentation and the IPRDs contained preliminary training requirements, it was the responsibility of the Training IPT to develop and define training concepts, guides, and jointly agreed-upon plans to ensure the successful completion of the NASA *Mir* Research Program. Through joint working group and U.S.-based training sessions and discussions, the Training IPT established jointly agreed-upon training concepts, principles and increment-specific training plans. Changes and modifications to the increment level training requirements were under the jurisdiction of the MOIWG CCB, and implementation was coordinated through joint MOIWG meetings and protocols.

In executing payload training, two U.S.-based training sessions were identified during the mission preparation phase of each increment. This served to complement continuous crew training ongoing at GCTC, based on the availability of crew training hardware of required fidelity. Indeed, training hardware destined for Russia underwent acceptance testing, requiring the presence of GCTC specialists to familiarize themselves with training units, verify training and flight hardware fidelity, and experiment procedures. Training lesson plans for each session were developed, and session evaluation logs were compiled to assess the effectiveness of each session, and as a method of continuous process improvement. Sessions involved U.S. science experts, RSC-E experiment curators, GCTC crew instructors, and crew procedure developers. Flight crew training was held on both an individual and group basis, supporting prime and backup flight crew requirements, as well as requirements for operators and subjects. While in Russia, weekly payload training sessions were held in compliance with the jointly agreed-upon increment training plan. At GCTC, available integrated *Mir* and module simulators, including specialized hardware stands, were used for theoretical and practical crew training. Moreover, all EVA training for external payloads was performed at GCTC. Medical discipline science crew training not only utilized the joint resources established at GCTC, but also required close coordination with IBMP specialists. Through the early identification of refresher and proficiency training, and the tools required to support this, such as Computer Based Training and Field Deployable Trainers, both on the ground and on orbit, a high degree of proficiency was achieved prior to execution on orbit.

To take advantage of PED and hardware efficiencies, the Ground Controller Training Program was conducted in parallel with the U.S.-based crew training sessions. Supplemental training was provided at JSC.

Crew readiness for the science program implementation was determined based on the results of test training sessions.

5.2.4.3 Joint Accomplishments

The Spektr incident and late crew changes proved that the developed training processes were flexible, yet structured enough to hold up under changing programmatic conditions.

Meeting the goal of efficient, effective training required close coordination with Russian counterparts and U.S. training personnel in Russia to maintain continuity and consistency of training plans for U.S. and Russian sessions across increments. Negotiations often resulted in specialization of cosmonaut crew members, procedures reviews, consolidated requirements, and revision of planned training hours.

Coordination of training schedules with hardware and procedure development schedules proved to be critical to the success of training. In later increments, improved working relationships, streamlined processes, and reflown experiments made such coordination possible.

Streamlined processes also allowed for the effective accomplishment of Ground Controller training in conjunction with crew training, and for the development of various innovative training methods and materials, such as computer-based training for on-orbit use.

The development of NASA/*Mir* payload training processes allowed for the successful training coordination of an entire program across several increments, and even on an international basis.

Indeed, continuous process improvement led to a streamlining and improvement of the negotiation process, and the ultimate synchronization of the procedure development process with the training schedule. Development of upgraded training and laboratory facilities at GCTC in support of program research disciplines.

5.2.4.4 Joint Lessons Learned/Future Applications

The experience of long-term spaceflight has demonstrated the need for active participation by the crew in the research and experimentation aspects of scientific investigations. This is achieved through the accumulation by the crew of the scientific aspects of the phenomenon under study and the basic principles behind the science hardware, its design and functionality.

The criticality of outfitting of trainers and mockups cannot be understated. It essential to support integrated payload training, on both a system and element basis. The certification of training units in ground utilization needs to be clearly defined, being sure to address safety and hardware fidelity to flight units.

In order to continuously improve crew training for the science experiment and research program execution, the training process must be updated on a continuous basis based on experiment results from previous and ongoing missions. This will require trainers to be updated with the latest experiment results and reports.

Development of operations documentation in support of crew training is critical, and integrated schedules must be developed which allow for this close coordination.

5.2.5 Operations IPT

5.2.5.1 Executive Summary

The MOIWG Operations IPT was tasked with providing operational evaluations and assessments of payload requirements, defining and developing mission preparation activities and products, providing real-time mission execution in the U.S. and Russia, and developing postflight assessments and reports.

5.2.5.2 Structure and Processes

In satisfying these requirements, the Operations IPT was structured to support increment-based teams as well as provide the operational products required for each and every mission. Thus, there existed a core group of operations specialists who provided data and communications support, systems engineering, procedure development, flight planning and operational assessments and requirements. Also, the Operations IPT was tasked with providing *Mir* systems insight in support of the overall NASA *Mir* Program, and in preparation for ISS. In its implementation, the Operations IPT provided support teams of rotating personnel for the two Mission Control Centers that jointly managed the real-time missions. Close coordination with the MSWG operations support was required to ensure implementation of NASA/*Mir* Research Program requirements. The POSA, located in the Mission Control Center (MCC-H) at JSC, served as the U.S. operations integration facility for NASA/*Mir* mission operations, and the Spaceflight Control Center (TsUP), located in Moscow, served as the interface to the *Mir* Flight Control Team and the U.S. long-duration crew member.

The mission operations processes were based on the Russian long-duration system for the development of nominal flight plans, research and experiment plans, daily flight plans, procedures development and implementation, including real-time updates, data and communications sessions, and telemetry data processing and distribution.

In implementing these tasks, the Operations IPT worked through periodic Phase 1 Program meetings, joint MOIWG meetings and standalone flight planning and mission product discussions and teleconferences. Moreover, due to the operational nature of the roles and responsibilities, frequent and routine interface with STS mission operations personnel and the MOIWG Mission Management IPT was required.

5.2.5.3 Joint Accomplishments

In the implementation of these tasks, the Operations IPT interfaced directly and continuously with Russian counterparts during the course of the program in these areas, developing a working relationship that directly led to the operational success of each increment.

Development of a process for tracking the orderly packaging and return of the scientific data products from long-duration missions.

The establishment of a Photo/Video Coordination Group to provide a complete set of photo/video hardware and consumables for all payloads was beneficial to the program. By consolidating the photo/video stowage effort, all film was returned, used or not, to ensure no photo/video data was stored on film that had been degraded by excessive amounts of radiation. In addition, the expert advice on photo/video planning, crew training, procedures, and products ensured success when conducting joint activities.

Development of a process for providing operational assessment of payload requirements and implementation of these requirements on the *Mir*-OS through flight plans, procedures, and supporting operational documentation.

Evolution of a crew onboard procedure development and implementation process that served to support hardware integration schedules, crew training plans, and mission operations requirements.

Development of a mission nominal flight plan, based on launch schedules for manned and cargo vehicles, plans for science and engineering experiments, and with regards to resource and environmental constraints during the course of the mission. Further development of a two-week plan addressing daily work distribution and accommodating real-time changes in status of flight systems and vehicle resources. Final development of a Detailed Flight Plan, detailing daily operational program covering station systems, crew, and ground control facilities.

Development of a Daily Assignment Plan in English and Russian, to communicate to the flight crew current daily schedules and plans.

Development and establishment of a 6.5-hour crew workday for planned payload flight operations, excluding medical operations requirements.

Development of daily research program reports, and weekly *Mir* system status reports.

Development of a plan of action for addressing anomalous conditions in payload hardware, given limited communication with on-orbit vehicle and differing work schedules and hours between the U.S. and Russia.

Development and implementation of a plan for utilization of U.S. ground communication sites in support of *Mir* on-orbit operations. These sites were used for air-to-ground (A/G) voice and telemetry operations.

Utilization of Russian A/G communications and telemetry in support of NASA *Mir* operations for medical, payload, and public affairs operations.

5.2.5.4 Joint Lessons Learned/Future Applications

Development of integrated, coordinated procedure development process, taking into account integration and training requirements and schedules.

Development of close working relationships between flight controllers from distant sites and cultures.

Establishment of routine process for review and unlink of messages to flight crew from differing control facilities.

Development of a flight planning process based on NASA-*Mir* lessons learned, utilizing design (pre-mission) and real-time (in-flight) planning. Need to make allowances for experiment setup, deactivation requirements, photo/video setup sessions, hardware anomalies, etc.

Enhanced A/G communications in support of on-orbit operations, including greater use of satellite communications, and expanded ground support networks.

5.2.6 Integration IPT

5.2.6.1 Executive Summary

The primary challenge for NASA/*Mir* Integration was to provide quality payload management, processing, and delivery while adapting to changing technical and programmatic requirements and adjusting to cultural obstacles. The organization also designed, certified, and delivered shared hardware equipment for use by multiple users on the *Mir*-OS. The planning and implementation of payload integration for NASA/*Mir* required careful analysis of payload technical requirements, successful management of the acceptance testing (AT) process, effective coordination between payload providers and vehicle managers, and timely delivery and integration of payloads to the appropriate carrier elements.

The success of the payload integration task can be traced to the solid working relationships developed between integration personnel, payload developers and the Russian technical specialists. These groups were able to integrate different philosophical and historical approaches to design and testing so that the ultimate goal of launching and operating science payloads was always kept in focus. The processes developed to attain these goals were tested and refined as the program progressed, resulting in a well-defined set of processes that can be applied to future crewed spaceflight programs.

5.2.6.2 Structure and Processes

The programmatic and technical requirements imposed upon the NASA/*Mir* program were documented in the US/R-001, Plan for Managing the Implementation of the NASA/*Mir* Science Program, and the US/R-002, Hardware General Design Standards and Test Requirements. These documents contained the required processes, document blank books and the technical design requirements for hardware operating aboard the *Mir* Space Station. Each of these documents went through extensive joint review to develop a mutually agreed-upon set of requirements.

The MOIWG Integration IPT was responsible for ensuring that all payload hardware was certified for flight aboard the U.S. and/or Russian launch vehicles, and that all required documentation was complete, with the overall objective and goal of ensuring that no hazardous conditions existed for the crew or station. Integration documentation prepared for the NASA/*Mir* program consisted of the following jointly signed documents:

100 - Hardware Development Requirements
101 - Equipment Technical Description
103 - AT Procedures
104 - Incoming Inspection and Performance Checks
105 - Certification Test Procedures
106 - Certification Test Protocols and Reports
107 - Safety Report and Findings
109 - Technical Description of Test Hardware

In addition, Dimensional Installation Drawings (DIDs), Electrical Interface Drawings (EIDs), ACTs (Russian certification statements) and 100 passports were also required. Documents were updated based on certification results, and in the course of AT-1 and AT-2. The span of this responsibility covered various Progress flights beginning with Progress 224 in August 1994, all NASA/*Mir* Space Shuttle flights beginning with STS-71, Soyuz launches during the NASA/*Mir* program and the two Russian modules, Spektr and Priroda. This work proved to be very challenging since it required integrating requirements and processes from the U.S. and Russian programs. Each side utilized a similar structure with an Integration lead and technical specialists associated with each payload, including Russian curators and U.S. payload engineers.

Acceptance testing of hardware to verify compliance with the hardware development requirements, and to authorize manifesting aboard the *Mir*-OS was accomplished via Acceptance Testing procedures (ATs). This process included jointly reviewing all of the technical documentation and test data and physical inspections of the hardware, and documenting the results through jointly signed protocols. AT activities occurred at JSC (AT-1) and Moscow (AT-2) as well as at the launch facilities at Kennedy Space Center and Baikanour (incoming inspections). Incoming inspections were performed with respect to hardware that was modified following AT, in cases where the final hardware processing for flight had a negative effect on its safety, or on hardware that had originally failed previous ATs. In the cases of defects or failures, a defect analysis protocol was compiled together with a plan of action including a partial rerun of the acceptance tests. AT activities for Progress, Soyuz and Shuttle flights primarily consisted of joint testing and documentation review with the physical integration of the hardware aboard the launch vehicle being the responsibility of the vehicle owner. The AT process continually improved over the NASA/*Mir* program and culminated in agreement on AT by Accompanying Documentation (AD) which allowed reflown hardware to be accepted without joint inspection or documentation review.

Previously flown hardware, that had not undergone modifications, was accepted for flight based on cover documents; the U.S. side performed acceptance testing internally, in conjunction with U.S. Quality Assurance requirements, and accompanying documentation was submitted for review and approval by the Russian side.

Safety approval for payloads flying aboard the *Mir* Space Station proved to be an evolving process. The Russian side had an extensive knowledge of long duration effects and hazards that had to be incorporated into the U.S. hardware design primarily in the materials area. Safety was originally worked independently by both the Joint Safety Assurance Working Group, WG-2, for vehicle safety and by WG-6 specialists for payload safety, each through a different set of documentation: Safety Analysis Reports (SARs) and Safety Certificates for WG-2 and the 107 document for WG-6. This dual path continued for the first 5 Increments, but these two documents and processes were combined for the last 2 flights in order to provide efficiency and to ensure consistent requirements review.

Stowage and hardware manifesting were managed through the US/R-004 document, Configuration and Status of U.S. Hardware on the *Mir* Station. This document contained information on the launch and return manifests for each Space Shuttle flight as well as on-orbit information for hardware aboard the *Mir* Space Station. This manifest was ultimately used to define the list of hardware requiring AT activities.

5.2.6.3 Joint Accomplishments

The evolution of the safety process from the independent SARs and 107 document into one document which was reviewed and approved by both WG-2 and WG-6 was representative of the teamwork and cooperation demonstrated during the Phase 1 Program. This change increased the efficiency of the safety process and the approval time for payloads aboard the *Mir* Space Station.

The design, delivery and integration of interface hardware as well as the integration of science payloads into the Spektr and Priroda modules was a monumental step in the Phase 1 program. These modules allowed the expansion of the science program and demonstrated the technical accomplishments that were performed during the program. The requirements definition, design to fabrication, and final testing processes that were developed for Phase 1 were examples of these accomplishments. All these achievements were a result of the intense technical and programmatic negotiations among multiple interagency and international partners that were driven by tight development and launch schedules.

The development of the AT by AD process represented an example of the relationships built between the U.S. and Russian sides. Initial AT activities were long and arduous processes requiring very detailed reviews of the hardware and documentation. The AT by AD process was based on the improvements made during each AT. This process led to cost savings by reducing the duration of AT activities and the number of personnel required to support them.

The development of shipping/logistics processes to and from Russia required a significant amount of coordination with Russian specialists, customs officials, JSC transportation and U.S. Embassy officials. It also required shipping/logistics personnel to maintain cognizance of all domestic and international export/import regulations. The successful implementation of these processes resulted in timely deliveries of flight and training hardware for tests, training and launch aboard Russian vehicles.

The establishment of a liaison office in Moscow to work as a direct interface between the U.S. and Russian sides improved the ability to transfer information and products. This office was extremely helpful in coordinating document approvals and hardware deliveries for Russian vehicle launches.

The integration of the Spektr and Priroda modules was a fully joint effort with both sides contributing to the design activities and physical integration of the modules. Electrical power, mechanical and data telemetry interfaces to the Russian systems were designed and developed.

5.2.6.4 Joint Lessons Learned/Future Applications

It is critical that integration documentation be prepared and delivered prior to delivery of the flight hardware for acceptance testing. Delays involved in the review of integration documentation unnecessarily prolong the AT process, and can be easily avoided by strict adherence to delivery schedules. This also applies to adherence to certification testing schedules and documentation.

It is essential that integration and operations personnel be involved in the early stages of hardware development and verification, in order to facilitate hardware acceptance and improve equipment operations and safety. The use of flight units to support certification testing can lead to hardware reliability issues, and thus should be minimized.

Cosmonaut Yuriy Gidzenko, astronaut Ken Cameron, cosmonaut Sergei Avdeyev, and astronaut William McArthur, shown working on board the *Mir* during STS-74

NASA 1 astronaut Norm Thagard

Section 6 - Safety Assurance

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6.1 Introduction

In 1994, an agreement between NASA and Russian Space Agency management (WG-0/RSC-E/NASA/0001) created a number of joint working groups for the real-time resolution of issues across all major disciplines. As one of these groups, the Joint Safety Assurance Working Group (JSAWG) was created whose objective was the evaluation of safety requirements for the Shuttle-*Mir* Program.

In accordance with the agreements made, this was an integrated, multifaceted program and was responsible for three primary objectives:

1st objective: Flights of Russian cosmonauts on STS-60 and STS-63. During these flights, the Russian cosmonauts participated as crew members and took part in operations, research and experiments connected with meeting the objective of independent flight of the Shuttle.

2nd objective: Flight of an American astronaut on the Russian Soyuz TM vehicle; docking of the vehicle to the *Mir* station; and extended work of the American astronaut as a crew member on board *Mir*. During this flight the American astronaut participated in operations, research and experiments connected with fulfilling the flight objectives. The American astronaut was returned to earth on board STS-71 after completion of a joint flight under the Shuttle-*Mir* Program.

3rd objective: Joint flight of the STS-71 Shuttle and the *Mir* orbital station during which the Shuttle would dock with the station and Russian and U.S. cosmonauts would conduct joint research, experiments, and other operations. Each of these objectives had its own safety assurance features.

During the course of this program it became clear that expansion of the functions of the JSAWG was essential. The JSAWG became responsible for analysis of off-nominal situations on board the *Mir* and the Shuttle, for the safety review of cargo delivered to the station, for the safe functioning of scientific hardware, and for safe conduct of operations, etc.

The work of the JSAWG began with the development of the joint principles for ensuring safety, the development of the structure and content of safety documentation and the determination of scope and status for the JSAWG.

6.2 Documentation Structure

A joint basic document WG-2/NASA/RSC E/003/2000 was developed entitled "Joint Safety, Reliability, and Quality Assurance Policies for the Shuttle/*Mir* and NASA/*Mir* Programs" (document 3-1 in Figure 6.1).

This document set forth:

- general provisions for evaluation and verification of safety during implementation of the programs;
- main technical requirements which have to be fulfilled in order to ensure mission safety;
- structure of joint documentation release and exchange of safety program documentation.

The structure of all safety documentation developed by the JSAWG is presented in Figure 6.1.

The set of documents developed by the JSAWG reflected the joint work and effort of both sides for implementation of an integrated and effective safety assurance program for *Mir* and Shuttle.

6.3 Policies and Ground Rules

As a basis for confident resolution of the objectives presented with minimum accepted risk for both sides, the following were taken into account:

- Russian and U.S. experience and knowledge accumulated during space exploration;
- Russian experience accumulated during the assurance of the safety of Salyut and *Mir* orbital stations, and Soyuz and Progress vehicles;
- U.S. experience accumulated during the assurance of the safety of Space Shuttle, payloads, and Skylab missions;
- analyses and reviews performed to assess the safety of systems, Space Shuttle and *Mir* interfaces, and operations, both nominal and off-nominal. These analyses and reviews will also ensure that documentation developed for these missions implement jointly and individually identified safety measures.

Also, as a basis of each side's responsibility, the following principles were assumed:

- During the joint program, both sides are governed by the basic desire and intent not to inflict damage to each other's crew or hardware;
- The side installing hardware in the other side's spacecraft is responsible for impact of such hardware on safety of the mission within the scope of established requirements;
- The Russian side is responsible for ensuring the flight safety of the U.S. astronaut on the Soyuz TM and the *Mir* (including the long-term presence of the U.S. astronauts aboard the *Mir* station). The criteria, process, and requirements for the continued presence of the U.S. astronauts on board the *Mir* are delineated in the International Space Station (ISS) Phase 1 - Program Directive;
- The U.S. side is responsible for ensuring the flight safety of the Russian cosmonaut on the Shuttle;

- The U.S. side is responsible for safety during Shuttle proximity and docking operations until the initiation of the mechanical interface of the two vehicles is achieved. During operations, the Russian side shall maintain required and agreed-upon conditions for docking.
- Both sides are responsible for the safety of the joint mission. However, the Russian side is responsible for the safety of the mixed crew on *Mir*, whereas the U.S. side is responsible for the safety of the mixed crew on Space Shuttle. In the event an off-nominal situation arose, the U.S. astronauts would return to the Shuttle, and the Russian cosmonauts would return to *Mir*.
- The supplying side is responsible for the safety certification of the experiments, hardware and logistics which are to be transported or operated on U.S. and Russian spacecraft. If these experiments, hardware, or logistics have hazard potential, their safety must be certified by both sides.

The JSAWG developed the main provisions for safety assurance procedures which, in particular, provided for:

1. Safety assurance procedures, in accordance with which the safety requirements that were developed for earlier design phases of both space vehicles (Shuttle and *Mir*), were used to develop hardware as well as methods for quality control and testing. The effectiveness of safety procedures developed has been confirmed by extended use of both vehicles.

2. Joint analysis of joint flight operations and possible off-nominal situations and the development of real-time measures to control or to reduce the degree of risk.

3. The development by each side of off-nominal situations and hazardous factors (harmful effect to the habitable environment, hazardous radiation levels, external effects of space events, etc.) for the vehicle and for equipment located in the other side's vehicle. The hazard criteria were the effects of reviewed factors on crew safety, vehicle functionality, and completion of the main flight objectives.

4. Joint analysis of off-nominal situations for each side and development of a joint document that contains a listing of off-nominal situations that require joint actions to prevent them.

As the Program was expanded to multiple Shuttle/*Mir* missions, the JSAWG developed a separate set of documents for each mission, which addressed the above provisions, ending with the Joint Certificate of Flight Readiness (COFR).

Following management's decision about transferring the safety issues for payloads delivered to *Mir* and the safe functioning of scientific hardware on board *Mir* to the JSAWG, main provisions were developed for payload safety (including scientific hardware) and were documented in the "Safety Certification Agreement for Transport of Logistics and Hardware in a Pressurized Volume to and From the *Mir*" and the "Safety Certification Agreement for Experiment Hardware Operations On Board the *Mir* and Shuttle." Basic requirements were also developed for the documentation for hardware safety (document WG-2/RSC-E/NASA/2100), including the format of the safety certificates, their content, and the requirements for the hazard reports.

Based on these documents, the JSAWG performed a safety analysis of all payloads including scientific hardware transported both on Russian vehicles and the Shuttle and also conducted a safety analysis for operating and stowing these payloads on *Mir*. Each side published summary documents containing a complete list of payload safety certificates.

Based on a Directive from Team Zero, the JSAWG conducted safety assessments for the U.S. astronauts' long-duration missions on *Mir*, taking into consideration activities on board the *Mir* Station.

All of the above came together as an effective, integrated safety program for Phase 1. From initial evaluation of safety requirements to the certification of flight readiness for each mission phase, safety was assured through this comprehensive safety program.

6.4 Top Safety Joint Accomplishments

6.4.1 Preface

A significant number of design changes and operational modifications were implemented as a result of joint participation between the Russian and American partners in the JSAWG. One of the Lessons Learned engendered most of these changes, i.e. "When multiple spacecraft are on orbit, new families of requirements are created and require assessment - each orbiting spacecraft imposes specific added requirements on the other." For ease of discussion, the accomplishments have been grouped into four categories: Hardware Changes, Integrated Analyses, Joint Flight Rule Changes and Safety Operational Contributions.

6.4.2 Hardware Changes

This category summarizes those risks that were identified in the joint safety process which resulted in modifications and/or changes to flight hardware. The majority of these changes were implemented on the American side. The primary focus was not to redesign existing hardware on either side but to make modifications as necessary to enhance the safety of Shuttle/*Mir* operations.

1. Modification of Criticality 1 ODS Connectors

Due to the existing design of Russian avionics boxes, the primary and redundant capabilities (i.e. main power buses, logic buses, etc.) are routed through the same Russian docking mechanism connector, which violates NSTS 8080-1, Standard 20, Redundant Electrical Circuits. The JSAWG recommended, and action was taken, to separate the primary and redundant capabilities on the American connector side of Russian-American wire harnesses. This implementation mitigated potential single-point failures (i.e. inadvertent demate of connectors) which could cause risk to the crew or vehicle during on-orbit phases.

2. Hatch Installed for STS-74, -76, -79, and -81 to Protect for Separation Redundancy

The hazard analysis for STS-71 identified that loss of pressurization in the ODS/tunnel adapter could compromise the operations of the avionics associated with the ODS structural hook opening, as well as the ability to perform the 96-bolt contingency extravehicular activity (EVA). The JSAWG recommended the addition of a hatch between the internal airlock/tunnel adapter and the ODS external airlock to isolate the two compartments and maintain redundancy for Shuttle/*Mir* undocking. This change was implemented for STS-74 through STS-81, thereby eliminating the risk of a single failure that could cause loss of both primary and contingency undocking capabilities.

3. Tool Developed to Manually Release Capture Latches

During Safety evaluation of contingency operations for Shuttle/*Mir*, a new contingency was identified wherein the capture latches would not release and the guide ring could not be retracted. An internal EVA was evaluated in the Weightless Environment Training Facility (WETF) and it was determined that a special tool to release the capture latches was required. The tool was developed and has been flown on all missions since it became available.

4. Wrenches Added to Allow Disassembly of Hatches From Either Side

To protect for the situation where the *Mir* hatch could not be opened after docking, a Russian hatch tool was flown on board the Shuttle and the crew was trained for *Mir* hatch opening. In light of the STS-80 hatch failure and the potential impact to the resupply of the *Mir* by the Shuttle, as well as the inability to perform an astronaut exchange, a joint off-nominal situation (ONS) assessment was performed to determine if appropriate tools and procedures are available for the U.S. astronaut on *Mir* to open the Orbiter hatch from the *Mir* side if necessary. It was determined that existing tools which had been delivered to *Mir* for a NASA payload were available to open the Orbiter hatch from the *Mir* side. It was verified that the U.S. astronaut on *Mir* was trained to open the hatch using existing procedures documented in the Johnson Space Center (JSC) EVA checklist.

5. Elimination of Single-Point Failures on Payload Equipment

Safety discovered and required the elimination of single-point failures from the thermoelectric holding facility fans, the Thermoelectric Freezer (TEF), and the Shuttle Orbiter inflight food warmer.

6.4.3 Integrated Analyses

The Russian and American partners performed safety analyses to identify risk components associated with Shuttle-*Mir* operations. By the completion of the Program, a total of 27 hazard reports containing 100 hazard causes were developed for the Shuttle while 16 hazard reports covering 57 causes were prepared for the *Mir*. One of the most significant benefits of these analyses was to identify aspects of the risk components which required the participation of both the Russian and American sides for resolution.

1. Identification/Resolution of Items for Joint Consideration

Through the hazard analysis process performed by the U.S. and Russian specialists, a methodology was developed to identify and resolve safety items requiring joint consideration. This effort led to the identification of additional required integration analyses, as well as the definition of requirements for joint operational and contingency procedures. This process also included a methodology to perform a closed-loop joint verification of each hazard control.

2. Exceedance of Mated Shuttle/*Mir* Load Constraints

During the evaluation of the *Mir* Structural Dynamics Experiment (MiSDE), an issue was identified that the *Mir* structural loads constraints would be exceeded in the event of a primary thruster failed "on" in a continuous firing mode. The JSAWG then identified the need for specific loads analysis of failed-on primary reaction control system (PRCS) jets. Analysis results indicated the potential for exceedance of interface load constraints within the response time capability for manual crew power-down of the failed jet. This led to the development of a flight rule defining priorities for mated attitude control and a requirement for PRCS reaction jet drivers to be powered off except when needed, and the definition of safety rationale for performance of the MiSDE.

3. Use of Iodine-Based Water on the *Mir*

During the STS-71 review of Shuttle-*Mir* safety, the Russians expressed a concern about mixing the iodine-treated water with the silver-treated water on *Mir*. Procedures were developed by which the transferred water was filtered through an iodine removal cartridge.

4. Halon Fire Suppression Toxicity Issues

During development of the STS-71 Shuttle/*Mir* integrated hazard analysis, a joint hazard was identified due to the potential release of halon into the mated spacecraft. Accidental discharge and leakage of halon is controlled by design and preflight checkout of the fire suppression system. Several analyses were performed concerning the release of halon into the habitable volume, including that of thermal decomposition of Halon 1301 and the effects on humans. Joint operational rules and procedures were developed concerning fire on board Shuttle/*Mir*. It was determined that, in the event of a fire, hatches will be closed before executing firefighting procedures.

5. Bounce-Off and Other Collision-Related Issues

Contingency situations such as bounce-off during docking- and collision-related issues such as clearance were documented and carried as open issues in the integrated hazard analysis until action was taken to eliminate those operational hazards or they were elevated to management as risk issues. The JSAWG has worked closely with the dynamics personnel both at Boeing North American and NASA to evaluate the contingency situations and ensure that operational controls have been implemented to reduce the hazard potential and that crew training for these contingency situations has been accomplished. In situations where the requirements of the Orbiter specification have not been met, waiver action was submitted to management for approval.

6.4.4 Joint Flight Rules

1. Safe Jettison of Hardware

The hazard analysis for the STS-74 docking module (DM) mission highlighted the need to establish operational constraints on hardware jettison while in the same orbit as *Mir*. This led to the development of an NSTS 18308 flight rule, X20.4.0-8, and although eliminated during the operational documentation update for a later mission cycle, the closed-loop verification of the JSAWG safety process drove the reinstatement of the rule as a hazard control for potential collision with jettisoned hardware.

2. Constraints on Viewing of Lasers

The JSAWG hazard analysis which assessed crew injury during Shuttle/*Mir* missions identified a hazard concerning potential laser injury to the crew. Subsequent analysis determined that for trajectory control sensor (TCS) operations in the pulse mode, there is no potential for eye damage due to adequate distance between the TCS laser unit and the *Mir* crew view port. Failure modes for TCS continuous wave operations were also analyzed, and were considered to be precluded by design because they required three failures. The handheld lidar is not hazardous to the unaided eye when in use. Finally, the *Mir* crew identified operational constraints for use of optical hardware when the Shuttle is within 10 meters. All of the operational constraints are documented in NSTS 18308, X20.4.2-5.

6.4.5 Safety Operational Contributions

1. Established Criteria for Restow Versus Jettison of DM in the Event Rapid Safing is Required

STS-74 was a delivery and assembly flight of the DM to the *Mir*. The DM was launched in the Shuttle payload bay, removed by the remote manipulator system (RMS), installed onto the Shuttle ODS, and finally docked to the *Mir*. The JSAWG developed time lines for rapid safing to determine at what point the DM could be restowed, or needed to be jettisoned in order to ensure a safe emergency return of the Shuttle. These data were presented to the Payload Safety Review Panel which concurred with and approved the JSAWG criteria for "DM Rapid Safing."

2. Established Risk of Bailout to Long-Duration Crew Members

Prior to the STS-71 mission, several concerns were expressed regarding the ability of deconditioned crew members to egress the vehicle in a bailout situation and the likelihood of bailout with deconditioned crew on board. An analysis was conducted to determine the probability of a scenario where the Shuttle could not safely land but could be kept stable for a bailout. The study showed the likelihood to be 1 in 60,000. The recumbent seating and the bailout options were considered appropriate measures due to the remote likelihood of these being used.

3. Identified Shuttle as a Critical Component of *Mir* Resupply System
The basic elements of the *Mir*/NASA Program included cosmonaut flights on board Shuttle, Shuttle docking with the *Mir* to exchange NASA astronauts, conduct of long-term scientific research and experiments aboard *Mir*, and development of coordinated operations between Russian and U.S. flight control systems while performing joint flights. In this regard, the Shuttle was initially not an integral part of the *Mir* resupply plan. However, as the *Mir*/NASA Program progressed, and Shuttle flights were interleaved with Soyuz and Progress resupply missions, Shuttle flight readiness and mission success became critical to crew and station safety.

4. Established Requirement for 96-Bolt EVA for Contingency Separation
Early in the Shuttle-*Mir* Program and prior to the initial docking flight to *Mir*, hazard analysis of the ODS determined that the separation function for the vehicle stack was only single-fault tolerant by means of primary electromechanical and backup pyrotechnic mechanisms. The JSAWG investigated proposed options and was instrumental in initiating actions to develop a third means of separation by EVA removal of 96 bolts at the docking mechanism / docking base interface. This resulted in a two-fault tolerant system that complies with program requirements and mitigates the risk of failure to separate.

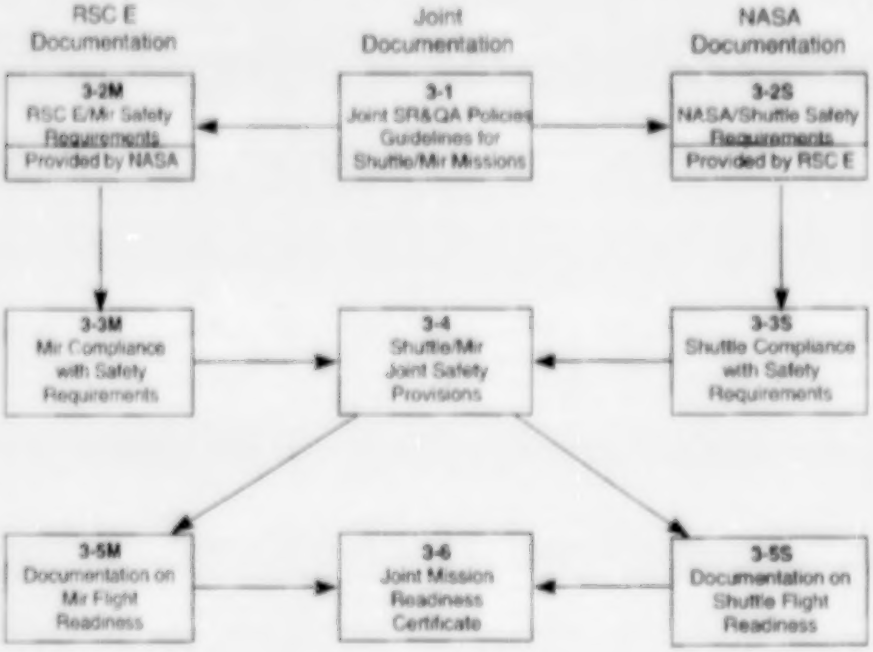
RSC E Documentation
Joint Documentation
NASA Documentation
3-2M
RSC E/Mir Safety Requirements
Provided by NASA
3-1
Joint SR&QA Policies Guidelines for Shuttle/Mir Missions
3-2S
NASA/Shuttle Safety Requirements
Provided by RSC E
3-3M
Mir Compliance with Safety Requirements
3-4
Shuttle/Mir Joint Safety Provisions
3-3S
Shuttle Compliance with Safety Requirements
3-5M
Documentation on Mir Flight Readiness
3-6
Joint Mission Readiness Certificate
3-5S
Documentation on Shuttle Flight Readiness

Figure 6.1: Joint Safety Assurance Working Group Documentation Structure

6.5 Top Safety Lessons Learned

The success of the Shuttle-*Mir* Integration Safety Program resulted from the joint efforts of both the Shuttle and *Mir* specialists working together from the Program's inception through its completion. In this regard, the safety criteria and requirements for each program were identified and exchanged so that a single program safety operating policy could be jointly developed to fulfill the needs and concerns for each side. This policy outlined the process and structure (see Figure 6.1) which delineated that vehicle specialists independently perform analyses to identify hazardous conditions and necessary control measures. Subsequent joint review and evaluation of hazard control measures were performed to identify items requiring joint action. These included joint verification analyses and, in particular, analyses and definition of joint operational measures required for real-time response to in-flight off-nominal situations. Based upon these efforts, individual and joint conclusions were developed to support joint safety certification of flight readiness.

The Shuttle-*Mir* Safety Program has demonstrated that the early involvement of safety specialists for each program element, and the active exchange of information by all concerned parties throughout the program duration, is essential for the identification and resolution of integrated hazards between programs and program elements.

1. Station to Shuttle Integrated Safety Analyses Performed by Both Parties
One of the significant analytical legacies for ISS application was the development and execution of a unique integrated hazard analysis process. A primary lesson learned during Phase 1 was the inability of a single side to identify, characterize and resolve those risks associated with multiple programs. This process involved participation by both Shuttle and *Mir* Station specialists to identify and resolve risks involved with the joint on-orbit operations. Individual programs initiated these analyses, and each party identified issues affecting their respective areas of responsibilities, as well as items requiring joint resolution. The team then worked together to identify the optimum solution(s) for the total program.

2. Operation and Transportation Safety Analysis of Payloads
A simplified safety certification process was developed for experimental equipment and logistics hardware for operation or transportation. Safety Certificates were developed which were signed by the developer, the co-chairmen of the Joint Safety Assurance Working Group and the Phase 1 Program Managers. The user and the transporter utilized this process for safety certifications for safe hardware transfer, delivery, and operations. This process provided the flexibility to use either country's launch vehicles for delivery of logistics, scientific experiments, etc., to the station. A unified certificate database was created to allow certification of reflight cargoes.

3. Joint Safety Assurance Working Group
The organizational cooperation plan (WG-0/NPO E/NASA 0001) signed by the program managers of NASA and RSC-E was developed at the beginning of joint activities of the Shuttle-*Mir* Program. This document officially established the joint

working groups, defined their tasks and responsibilities, and appointed the chairmen. Consequently, a JSAWG was established to provide a day-to-day forum for assessing and resolving risks between the two programs. The formal (4 to 5 times per year) face-to-face meetings, augmented by weekly teleconferences, ensured maximum involvement by both sides. An international partnership was formed which successfully worked through differences in cultural and engineering processes. This cooperative effort involved a methodical joint review and evaluation of each step of the integration process, from policy development through requirements definition and analysis of each aspect of the joint mission. The JSAWGenabled risk identification and resolution in an open and cooperative work environment that engendered joint teamwork, which resulted in a total risk management process.

4. Integrated Safety Documentation Structure
The Phase 1 Safety Program was guided by six facets of documentation (see Figure 6.1) providing safety policy, requirements, analyses, assessments of hardware and Certificate of Flight Readiness for all parties. Provisions existed for the Phase 1 Joint Management Working Group's approval of each of the six components on a mission-by-mission basis. The major contribution of this structure was the visibility into requirements implementation for all program participants.

The ownership of the structure by both partners engendered a climate of cooperation for the safety participants instead of a climate of defense which commonly is characteristic of review boards and panels.

5. Preplanned Contingency Operations Developed for Each Mission by Both Parties
Hazards and hazard causes that required the participation of both the U.S and Russian parties to mitigate or eliminate the risk were identified as items for joint consideration. These items were reviewed, in a joint forum, and specific real-time actions were defined and agreed to by both safety organizations. This resulted in the development of joint contingency procedures and requirements for flight rules and joint crew operations. These were a catalyst to drive operational measures to resolve or mitigate the ONS.

6. Creation of an Agreed-To Set of Critical Life Support Criteria
The JSAWG identified life support requirements for continuation of the American astronaut on the *Mir* including atmospheric pressure and composition, thermal conditions, food and water reserves, oxygen generation capability, and quantity/functionality of fire extinguishers, breathing masks. This criteria tool provided a method for all parties to evaluate the safety of the station for continued operations.

7. Joint Policy for Out-of-Scope Activities
As the Shuttle-*Mir* Program progressed, the necessity to define minimum safety parameters became evident for several issues including EVA, test of new hardware such as the Inspektor, and other "ad hoc" tests. The JSAWG created a Phase 1 Joint Management Working Group's (Team "0") Safety Directive to provide consistent safety policy and directions. This allowed the JSAWG to accommodate new issues and perform safety assessment of changes in the evolving program activities.

8. Real-Time Responses to Safety-Related In-Flight Anomalies

The hazard analyses performed by the JSAWG considered safety-related failures that had been experienced during flight for both the Shuttle and *Mir*. During Phase 1, the cooperative effort by both parties to deal with the experienced ONS of fire, failures of computers, chemical exposure, depressurization, loss of power, etc., further served as a basis for formulating emergency scenarios for the ISS. Contingency approaches and joint procedures developed for Phase 1 of the ISS can be used to establish station-wide policy for specific emergencies on Phases 2 and 3 of the ISS.

9. Development of Readiness Requirements for *Mir* EVA

Preparation for use of the Russian Orlan space suit by American astronauts and Russian cosmonauts resulted in NASA's development of methodology to identify the station-unique risks and certify EVA readiness for joint missions with joint program hardware. The process developed for Phase 1 EVA facilitates transition to similar operation on the ISS.

10. Multiple Orbiting Vehicles Impose Specific Added Requirements on Each Other

The concept of a system integration effort consisting of predefined requirements coupled with evaluation of only interfaces was recognized as being totally inadequate for on-orbit space operations. The value of this lesson is that the ISS requirements will vary on a mission-by-mission basis in three key areas; configuration (system interactions), interface, and operational protocols. Each of these areas is dynamic and changes on a mission-by-mission basis as well as within phases of a given mission. The provisions for identifying and considering items for joint consideration allowed the Shuttle/*Mir* Safety Program to maximize its value to the Phase 1 effort.

11. Safety Assurance of U.S. Astronaut During EVA

NASA learned very early that the Russian JSAWG membership did not include an EVA expert. The Russian Safety experts, while focused on safety concerns, could not address detailed EVA issues. Similarly, the Russian EVA experts are not safety engineers, and while focused on EVA concerns, the Russian EVA experts could not expend the resources requested by the Americans for a detailed safety analysis. This lesson learned has been addressed in a new joint working group for ISS.

From the Phase 1 Program, the American Safety EVA Team learned about Russian EVA hardware, how to work with limited engineering data, and to work within the EVA community to resolve issues. (The Joint EVA Working Group was an extremely useful and effective resource, and continues to be for ISS issues.) Prior to the Phase 1 Program, the experience of the American Safety EVA Team dealt with short-term Shuttle-based EVAs. With *Mir*, the EVA Team learned the issues associated with operating a long-duration space station, to work with aging equipment, and to "making do" with a given situation to complete unexpected tasks. Additionally, Russian and American EVA experts from Phase 1 are also working ISS, therefore the knowledge and relationships gained early on in Phase 1 are already in use.

12. The Joint Safety Analyses of the STS-74 DM Assembly Mission. The STS-74 mission required transport of the DM to the *Mir* in the Shuttle. The integrated hazards to the Shuttle and *Mir* were evaluated as the DM was transformed from a Shuttle payload to an extension of the ODS. Later in the assembly process the DM became a permanent part of the *Mir* Station. Attendant joint activities of the DM called for an integrated assessment by both the Shuttle and *Mir* programs. Since an operation performed by one spacecraft might have an adverse effect on the other, both programs needed to analyze the DM as an entity, address systems interaction and operations and resolve the unique assembly issues in terms of the safety of their respective vehicles. This mission and the attendant analyses were the first of this kind, representing the initial Shuttle/Station assembly mission. Specific hazards identified and the joint process developed to resolve them provide lessons learned which are directly applicable to Shuttle assembly missions which are planned for Phase 2 of the ISS Program.

6.6 Conclusions

The unparalleled successful experience in implementing the Shuttle/*Mir* program (ISS, Phase 1) has taught us how to assure the safety of complex operations in space in spite of intergovernmental boundaries. These operations included delivery and return of astronauts and scientific hardware to and from orbit, conducting rendezvous, docking, maintenance and repair on orbit, joint EVAs in open space, delivering consumables and scientific hardware from Earth, and other preparatory steps necessary for the future assembly and operation of ISS. The main objective of the ISS Program Phase 1 was the safety and well-being of the astronauts and cosmonauts during the successful performance of joint American-Russian experiments by the partners and the integration of the laboratory and habitable modules with the *Mir* space station.

The jointly developed safety and risk management programs have been effective in identifying and controlling risks, which will provide valuable lessons for the ISS Phase 2 Program. These lessons include the joint preparation of Station to Shuttle integrated safety analysis by both parties, payload operation and transportation safety analysis, and a pro-active JSAWG with a unique integrated safety documentation structure.

In spite of the fact that not only the joint work, but also the independent work, of Russian and American managers who were responsible for safety and their working groups allowed them to effectively identify and control risks, the most valuable experience from the Phase 1 Program was received as a result of the joint safety assurance efforts while executing these two independent crewed spaceflight programs. This experience includes station operations by a joint American-Russian crew taking into consideration the recommendations developed by the safety group, performing integrated joint safety analyses, safety analysis of payload operation and transportation, the activities of the JSAWG with its uniquely developed documentation structure, and includes among other things, preplanned actions for off-nominal situations jointly developed for each mission.

NASA 6 astronaut David Wolf during an EVA training session

Section 7 - Crew Training

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7.1 Overview of Crew Training

Working Group 5 – crew exchange and training – was a small group that consisted of two people from the Russian side (A. Alexandrov, Y. Kargopolov) and the American side (Don Puddy, through mid 1995, C. Brown, mid 1995-Present, and T. Capps).

The objectives of the group were to determine the duties and responsibilities of cosmonauts and astronauts when completing flights on the Shuttle and Soyuz vehicles and the *Mir* station, the content of crew training in Russian and in the U.S., and to developing training schedules and programs.

The group maintained a fairly standard work process. Periodic meetings were usually held alternating in Russia and in the U.S. Between meetings contact was maintained through the use of teleconferences and faxes.

To widen the operational interaction on joint flight training issues, a Johnson Space Center (JSC) office (NASA) was created at the Gagarin Cosmonaut Training Center (GCTC) where an American representative permanently worked.

This position, which was called the "Director of Operation, Russia" (DOR) was filled by a representative from the astronaut corps. He took part daily in resolving issues related to cosmonaut and astronaut training for joint flights and implemented the agreements and resolutions of WG-5.

The Crew Exchange and Training Working Group also defined the agreements for the placement of emblems on crew flight clothing. The number and type of personal articles permitted for crew members during flights on different vehicles, the content and schedule for postflight activities, and also any other issues on crew exchange and training or crew-related issues that did not enter the area of responsibility of other working groups. During their period of work, the group developed and managed the following documents:

Crew Exchange and Training Working Group Documents

Table 7.1

5000	Duties and responsibilities of the *Mir*-18 astronaut.
5001	Duties and responsibilities of cosmonauts on the Shuttle during flight STS-71.
5002	Duties and responsibilities of the STS-71 astronauts on the *Mir*.
5003	*Mir*-18/Shuttle science.
5004	*Mir*-18 astronaut's training plan.
5005	STS-71 cosmonauts' training plan for Shuttle systems.
5006	STS-71 astronauts' training plan on *Mir*.
5007	Critical Shuttle terminology.
5008	Critical *Mir* terminology.
5010	Cosmonaut's science training plan under the STS-71 flight program.
5011	Topics of symbolic activity and crew personal topics during flight STS-71.
5012	Crew members' personal and service souvenirs of the Phase 1 joint space program.

Table 7.1 Cont.

5013	Topics of psychological support for the *Mir*/NASA crews of the *Mir* complex. Packages and personal items.
5025	Dictionary (English-Russian) of U.S./Russia space programs.
5026	Dictionary (Russian-English) of U.S./Russia space programs.
5030	Crew emergency evacuation system.
5031	Habitable compartments hardware.
5032	Shuttle EVA systems.
5034	*Mir* EVA systems.
5035	*Mir* construction and systems for Shuttle crew members.
5101	Duties and responsibilities of *Mir* station crew members on the Shuttle.
5102	Duties and responsibilities of Shuttle astronauts on the *Mir* station.
5105	*Mir* station crew member training plan for Shuttle systems (mated configuration).
5106	Shuttle crew member training plan for the *Mir* station (mated configuration).
5200	Duties and responsibilities of astronaut crew members of long-duration *Mir* missions.
5201	Astronauts' training program for extended flights on *Mir*.
5203	Cosmonaut duties and responsibilities on Shuttle STS-84 (December 1996).
5204	Training plan for cosmonaut completing flight on Shuttle STS-84 (December 1996).
5205	Cosmonaut duties and responsibilities on Shuttle STS-86 (May 1997).
5206	Training plan for cosmonaut completing flight on Shuttle STS-86 (May 1997).
5207	Cosmonaut duties and responsibilities on Shuttle STS-89 (September 1997).
5208	Training plan for cosmonaut completing flight on Shuttle STS-89 (September 1997).
5209	Cosmonaut duties and responsibilities on Shuttle STS-91 (January 1998).
5210	Training plan for cosmonaut for flight on Shuttle STS-91 (January 1998).

When necessary the working group made the appropriate changes and additions to these documents.

Working Group 6 was responsible for the content of the U.S. science training.

The work of Russian-American crews on board the *Mir* began with the *Mir*-18 mission that included the participation of astronaut-researcher Norman Thagard, the first NASA astronaut to carry out a long-duration flight for the Shuttle-*Mir* program. Norman Thagard was launched on the Soyuz TM transport vehicle on 14 March 1995 and worked on the station as an astronaut-researcher for 115 days. STS-71 transported the *Mir* 19 cosmonauts to *Mir* and returned the *Mir* 18 crew to the Earth during July 1995.

The docking of Shuttle STS-76 on 24 March 1996 was the beginning of the continuous presence and operation on the *Mir* station of NASA astronauts as part of the NASA-*Mir* program.

NASA astronaut Shannon Lucid, operating under the auspices of the NASA-*Mir*-2 program, was transported to the *Mir* station approximately one month after the Russian crew of *Mir*-21 began operation on the station. Subsequently, five more missions were executed (NASA-3, NASA-4, NASA-5, NASA-6, and NASA-7). During that time, for the execution of American-Russian transport operations seven Shuttle dockings were performed with the *Mir*. The program entailing the continuous presence of NASA astronauts on the *Mir* station was completed on 8 June 1998 after the undocking of the *Mir* station and Shuttle STS-91.

The unique nature of astronaut training for the NASA-*Mir* program consisted of astronaut shift rotations on board the *Mir* that were executed using the Shuttle while the crews of the primary missions were operating on it and the rotation schedule of these crews differed from that of the astronauts. Thus, each NASA astronaut had to operate as a member of several primary missions. With such a rotation system it was not always possible to ensure the training of astronauts as part of all of the crews with which they would be working on board the *Mir*. The system of astronaut rotation on the *Mir* is presented in table 7.2.

In all, over the period of operations for the Shuttle-*Mir* and NASA-*Mir* programs, 9 NASA astronauts were trained at the GCTC for the performance of long-duration spaceflight on the *Mir* station (7 of them executed spaceflights). Four astronauts underwent training in EVAs (3 of them performed EVA operations in flight).

Two training sessions each were performed at JSC and at the GCTC for the performance of the joint Russian-American science program using the primary and back-up crews of *Mir*-18, *Mir*-21, *Mir*-22, *Mir*-23, *Mir*-24, and *Mir*-25.

Within the framework of the NASA-*Mir* program 5 Russian cosmonauts (Krikalev, Titov, Kondakova, Sharipov, and Ryumin) underwent training at JSC for Shuttle flights as part of American crews, and executed space flights (twice for Titov). The corresponding Shuttle flights are STS-60 -63, -84, -86, -89, and -91.

Nine Shuttle crews (STS-71, -74, -76, -79, -81, -84, -86, -89, and -91) underwent a week of training in Russia for the *Mir* station for joint activity with Russian crews. The Russian primary and backup crews of *Mir*-20-25 underwent training at JSC for one week for the Shuttle and joint activity with STS crews (6 times in all).

Training of Russian-American *Mir* crews and Shuttle crews concerning *Mir* systems and Russian cosmonauts concerning Shuttle systems was carried out in accordance with the approved training programs and on the basis of the experience of training for joint flights for the Shuttle-*Mir* program. The total duration of the training of each of the astronauts was to have been 14 months. However, due to changes in the program and delays in the assignment of astronauts, this condition was not fulfilled for some of the American astronauts.

7.2 Training of Astronauts in Russia

NASA astronauts were trained at the GCTC to perform spaceflight on the *Mir* scientific research complex as flight engineers-2. This was done in two phases:

- as part of a group of astronauts;
- as part of a crew.

Table 7.3 presents generalized data concerning the scopes and dates of NASA astronaut training with allowance for backup.

7.2.1 Training as Part of a Group (Stage 1)

Training as part of a group entailed:

- technical training for the Soyuz TM transport vehicle;
- practical classes and training sessions on Soyuz TM simulators and stands;
- technical training for the *Mir* orbital complex;
- practical classes and training sessions on station and module simulators;
- medical/biological training, including flights in "weightlessness," medical examination, and physical training;
- survival training under extreme conditions;
- independent training;
- Russian language study.

The organization, scope, and content of training, and its technical and methodological support enabled the following tasks to be accomplished:

- acquisition of fundamental knowledge concerning the principles of design, layout, and operation of the onboard systems of the spacecraft comprising the *Mir* orbital complex;
- development of fundamental skills for the performance of typical operations for the control and servicing of onboard systems;
- learning of concepts, terms, and abbreviations used in Russian space technology (including the flight data files of the *Mir* complex);
- learning of Russian language.

Data concerning the scope of astronaut group training are cited in table 7.4.

As a result of the successful performance of these tasks the main goal was achieved: The required level of professional astronaut training needed to continue training as part of a crew was provided.

In the postflight reports of the first astronauts who executed spaceflight in the NASA-*Mir* program, it was noted that during the process of the subsequent cooperation of Russia and the U.S. in the field of manned spaceflight under the NASA-*Mir* program, the effectiveness of the training of American astronauts and its results can be significantly increased if the following measures are implemented:

- It is advisable to update the Russian program of theoretical training (first of all, in the area of fundamental knowledge) with allowance for the level of professional training of the NASA astronauts and their experience in the execution of spaceflights;
- Technical training needs to be started when the NASA astronauts attain a sufficient level of Russian language learning, especially for its everyday usage. A more intensive study of the Russian language and its technical applications should be continued during the process of technical training;
- An optimal combination of theoretical knowledge and the independent work of NASA astronauts should be provided during the initial stage of training — when the level of Russian language study is not high enough. The duration of the theoretical classes should not exceed four hours (it is advisable that the rest of the workday be planned for independent work by the astronauts, for consultations, and physical training). During this stage it is especially important to have all the methodological materials in two languages: Russian and English.

7.2.2 Training as Part of a Crew (Stage 2)

Training as part of a crew entailed:

- technical training for the Soyuz TM transport vehicle;
- practical classes and training sessions on Soyuz TM simulators and system mockups;
- technical training for the *Mir* orbital complex, practical classes and training sessions on station and module simulators;
- medical/biological training;
- training for the NASA-*Mir* scientific research program;
- training for the EVA program;
- preflight training as part of crew;
- independent training;
- Russian language study.

Data concerning the scope of astronaut training as part of a crew are cited in table 7.5.

Joint training with crew members made it possible for the astronauts to successfully perform training program tasks as part of a crew — to develop skills at the necessary level to perform the following types of activity within the scope of functions conferred on a flight engineer-2:

- assure crew safety, including the execution of operations for emergency descent on the Soyuz TM transport vehicle;
- support the reliable operation of the onboard systems and equipment of the complex;
- perform work station organization;
- exchange information with the NASA consultative group at Mission Control Center (MCC)-Houston;
- perform research and experiments;
- perform household procedures and physical exercises using onboard facilities.

In the opinion of the Russian crew members and American astronauts that worked under the NASA-*Mir* program, during the phase of training as part of Russian-American crews, greater attention needed to be given to matters of the psychological compatibility of crew members. For this, a longer training period should be carried out for each crew with which an astronaut will be working on board the *Mir*. Joint training sessions for survival under extreme conditions would also contribute to this.

The backup system that was initially developed and approved by the sides stipulated the execution of a flight by an astronaut mainly as part of a crew with which he underwent backup training, which ensured a longer joint training of cosmonauts and astronauts. The cancellation of Scott Parazynski's training and the subsequent alteration of the astronaut team and the dates of their arrival at the GCTC did not allow the backup system to be fulfilled.

The results of the integrated examination training session determined that the main goal had been attained: the level of professional crew training proved sufficient for it to be cleared for spaceflight and for the performance of the science program on board the *Mir*.

Astronaut Rotation on the *Mir*

Table 7.2

Mission/ Astronaut	**Date work began on *Mir***	**Date work completed on *Mir***	**Period of operation as part of Russian-American crew**	**Total duration of operation on *Mir***	**Total duration of EVA**
NASA-1 Norman Thagard	⇑ Soyuz TM-20 3/16/95	⇓STS-71 7/7/95	3/14/95-7/7/95 *Mir*-18 (Dezhurov, Strekalov)	115 days	no
NASA-2 Shannon Lucid	⇑STS-76 3/24/96	⇓STS-79 9/26/96	3/24/96-8/2/96 *Mir*-21 (Onufrienko, Usachev) 9/2/96-9/26/96 *Mir*-22 (Korzun, Kaleri)	188 days	no
NASA-3 John Blaha	⇑STS-79 9/19/96	⇓STS-81 1/20/97	9/19/96-1/20/97, *Mir*-22 (Korzun, Kaleri)	122 days	no
NASA-4 Jerry Linenger	⇑STS-81 1/15/97	⇓STS-84 5/21/97	1/15/97-3/1/97 *Mir*-22 (Korzun, Kaleri) 3/2/97-5/21/97 *Mir*-23 (Tsibliev, Lazutkin)	126 days	4 hours 58 minutes
NASA-5 Michael Foale	⇑STS-84 5/17/97	⇓STS-86 10/3/97	5/17/97-8/14/97 *Mir*-23 (Tsibliev, Lazutkin) 8/14/97-10/3/97 (Solovyev, Vinogradov)	139 days	6 hours
NASA-6 David Wolf	⇑STS-86 9/30/97	⇓STS-89 1/29/98	9/30/97-1/29/98, *Mir*-24 (Solovyev, Vinogradov)	122 days	6 hours 47 minutes
NASA-7 Andrew Thomas	⇑STS-89 1/24/98	⇓STS-91 6/8/98	1/24/98-2/19/98, *Mir*-24 (Solovyev, Vinogradov) 2/19/98-6/8/98 *Mir*-25 (Musabayev, Budarin)	135 days	no

Scope and Dates of Training

Table 7.3

Mission Astronaut (backup)	**Dates of beginning/end of operation on *Mir***	**Training with Russian crew (backups)**	**Dates of astronaut training (in group, as part of crew)**	**Total hours of training in group, crew (as primary, backup)**	**Total training hours of astronauts**
NASA-1 Norman Thagard (Bonnie Dunbar)	⇑Soyuz 20 3/16/95 ⇓STS-71 7/7/95 (115 days)	*Mir*-18 Dezhurov, Strekalov	3/1/94-10/7/94 10/10/94-2/21/95	883, 845	1728
NASA-2 Shannon Lucid (John Blaha)	⇑STS-76 3/24/96 ⇓STS-79 9/25/96 (188 days)	*Mir*-21 Onufrienko, Usachev (Tsibliev, Lazutkin)	1/3/95-6/24/95 6/26/95-2/26/96	795, 1127	1922
NASA-3 John Blaha (Jerry Linenger)	⇑STS-79 9/19/96 ⇓STS-81 1/20/97 (122 days)	*Mir*-22 Korzun, Kaleri (Manakov, Vinogradov)	2/23/96-7/1/96 5/29/95-7/19/96 (4/14 months)	795, 503 \ 959	2257
NASA-4 Jerry Linenger (Michael Foale)	⇑STS-81 1/15/97 ⇓STS-84 5/21/97 (126 days)	*Mir*-23 Tsibliev, Lazutkin (Musabayev, Budarin)	9/23/96-12/6/96 \ 11/29/95-12/20/96 (2.5 \ 13 months)	765, 605 \ 1054	2424
NASA-5 Michael Foale (James Voss)	⇑STS-84 5/17/97 ⇓STS-86 10/3/97 (139 days)	*Mir*-24 Solovyev, Vinogradov (Padalka, Avdeyev)	1/13/97-4/9/97 \ 4/3/96-4/30/97 (3 \ 14 months)	899, 408 \ 840	2147
NASA-6 David Wolf (Wendy Lawrence)	⇑STS-86 9/30/97 ⇓STS-89 1/29/98 (122 days)		9/2/96-8/27/97 \ 9/2/96- 8/12/97 (12 \ 11.5 months)	1081, 614	1695
NASA-7 Andrew Thomas (James Voss)	⇑STS-89 1/21/98 ⇓STS-91 6/8/98 (135 days)	*Mir*-25 Musabayev, Budarin (Afanasyev, Treshchev)	1/16/97-12/5/97 \ 9/8/97-12/5/97 (10.5 \ 3 months)	982, 553	1535

Scope of Training as Part of a Group for U.S. Astronauts

Table 7.4

Mission/ Astronaut (backup)	Training for Soyuz TM TV		Training for *Mir*		Medical/ biological training	EVA training	Independent training	Russian lang.	Total
	Technical training (hours)	Training on simulators (hours)	Technical training (hours)	Training on simulators (hours)	(hours)	(hours)	(hours)	(hours)	(hours)
NASA-1 Norman Thagard (Bonnie Dunbar)	134	173	120	50	170	--	86	150	883
NASA-2 Shannon Lucid (John Blaha)	20	50	114	60	122	--	161	268	795
NASA-3 John Blaha (Jerry Linenger)	20	50	114	60	122	--	161	268	795
NASA-4 Jerry Linenger (Michael Foale)	26	21	114	34	132	--	152	286	765
NASA-5 Michael Foale (James Voss)	50	23	108	40	156	93	154	275	899
NASA-6 David Wolf (Wendy Lawrence)	77	91	54	22	153	--	172	349	918
NASA-7 Andrew Thomas (James Voss)	49	165	60	13	180	32	147	336	982

Scope of Training as Part of a Crew for U.S. Astronauts

Table 7.5

Mission	**Training for Soyuz TM TV**		**Training for *Mir***		**Medical/ biological training**	**EVA training (prim./ backup)**	**Training for science program (prim./ backup)**	**Preflight training (prim./ backup)**	**Indep. Training (prim./ backup)**	**Russian lang. (prim./ backup)**	**Total (prim./ backup)**
Astronaut (backup)	Technical training (prim./ backup) (hours)	Training on simulators (prim./ backup) (hours)	Technical training (prim./ backup) (hours)	Training on simulators (prim./ backup) (hours)	(prim./ backup) (hours)	(hours)	(hours)	(hours)	(hours)	(hours)	(hours)
NASA-1 Norman Thagard (Bonnie Dunbar)	35	90	128	68	94	4	311	80	11	24	845
NASA-2 Shannon Lucid (John Blaha)	80/ -	130/ -	141/ -	142/ -	180/ -	--	266/ -	24/ -	76/ -	88/ -	1127/ -
NASA-3 John Blaha (Jerry Linenger)	6/79	29/172	16/139	81/141	100/147	--	239/209	--	--	32/72	503/959
NASA-4 Jerry Linenger (Michael Foale)	13/49	20/206	26/84	81/97	60/153	46/75	303/230	--	--	56/160	605/1054
NASA-5 Michael Foale (James Voss)	14/18	22/50	22/102	46/78	62/110	4/57	142/339	--	41/48	55/38	408/840

Scope of Training as Part of a Crew for U.S. Astronauts

Table 7.5 Cont.

Mission	Training for Soyuz TM TV		Training for *Mir*		Medical/ biological training	EVA training (prim./ backup)	Training for science program (prim./ backup)	Preflight training (prim./ backup)	Indep. training (prim./ backup)	Russian lang. (prim./ backup)	Total (prim./ backup)
NASA-6 David Wolf (Wendy Lawrence)	10/ -	82/ -	126/ -	100/ -	71/ -	96/ -	121/ -	—	—	8/ -	614/ -
NASA-7 Andrew Thomas (James Voss)	18	58	78	77	144	64	104	—	6	4	553

Note: M. Foale additional group science training - 137 hrs.
A. Thomas additional group science training - 93 hrs.

7.3 *Mir* Station Systems and Soyuz TM Training

The goal of the technical training of astronauts was to provide the level of knowledge and primary skills for the operation of the onboard systems of the Soyuz TM transport vehicle and the *Mir* station necessary for the performance of training sessions on simulators within the limits of their functional duties.

During the technical training of astronauts for the NASA-*Mir* program, particular attention was given to the onboard systems that have a substantial impact on crew safety. These include the life support systems complex (КСОЖ), the thermal mode control system (СОТР), and the motion control system (СУД). Theoretical and practical courses were carried out for these as well as other onboard systems.

Special features of training for the life support systems complex (КСОЖ)
Theoretical and practical courses were performed concerning the control and servicing of the *Mir* life support systems complex (КСОЖ) within the full scope of the functions of the flight engineer-2.

Special features of training for the thermal mode control system (СОТР)
Practical courses were performed to develop the astronauts' skills for the execution of vital operations:

- filling the СОТР loops with gas and coolant;
- replacing the coolant in the СОТР loops;
- separating the interior СОТР loops;
- finding and eliminating leaks in pipelines, etc.;
- developing skills to prevent loss of condensate and for its collection;
- developing skills for setting up ventilation of the complex and individual modules depending on the actual temperature/humidity conditions;
- developing skills for the operation and servicing of the main condensate discharge lines: operation with БКВ-3 (air conditioning unit);
- operating with ХСА БО ТК;
- operating with БОВа;
- developing skills for monitoring and control of the СОТР taking into consideration its actual state

Special features of training for the motion control system (СУД)

- performance of theoretical and practical courses to study identified off-nominal situations in connection with the extended operating time of individual СУД units;
- performance of practical courses at RSC Energia (RSC-E) control and test station for the servicing and repair of the СУД to develop skills for replacing units and parts and switching electrical cables.

Special features of technical training for the Soyuz TM transport vehicle

The technical training of astronauts for the transport vehicle was performed taking into consideration their function as cosmonaut/researcher during the performance of operations for an ahead-of-schedule or emergency descent from orbit. Astronauts were given a general idea of the transport vehicle's onboard systems, the plan for the execution of descent from orbit, as well as practical skills for self-help using the КСОЖ, conducting radio communications with MCC, evacuating the spacecraft after landing (splashdown), and survival.

7.4 Training in the Soyuz TM Integrated Simulator

Astronaut Norman Thagard was inserted into orbit on board the Soyuz TM transport vehicle. For this reason, practical courses and training sessions were carried out with him as part of the *Mir*-18 crew for the performance of all the flight program phases within the scope of the functional duties of the cosmonaut/researcher.

Subsequently, NASA astronauts during the implementation of the NASA-*Mir* program were transported and returned to Earth on the Shuttle. For this reason, NASA astronauts underwent training for the transport vehicle flight program only for the execution of descent from orbit (including emergency descent) in the event of the emergency evacuation of the orbital station and were seated in the seat of the cosmonaut/researcher.

On the basis of these baseline data a typical training program was developed for NASA astronauts as crewmembers on the integrated simulator of the transport vehicle and for actions to take in off-nominal and emergency situations in order to perform the assigned tasks and assure flight safety.

The typical program provided for the fulfillment of the following requirements for the training of NASA astronauts for the Soyuz TM transport vehicle:

- An astronaut must be familiar with the transport vehicle design and layout and onboard systems;
- An astronaut must know how to execute an emergency evacuation of the *Mir* station as part of the crew, the actions to take to prepare for emergency descent in the event of fire, depressurization, specific flight data files, and have the following practical skills:
    - open/close СА-БО hatch, check to see that it is airtight;
    - operate personal protective gear (Sokol space suit, etc.);
    - operate the following valves: ЭПК-РД, ЭПК-ПСА, РПВ-2, 3В valve: (СА condensate - БО condensate);
    - output commands from the right control panel (КСП).
- An astronaut must know how to use the telephone communications system (to conduct radio communications), the water supply system, and the wastewater system.

The typical training program entailed the following:

1. Program for the performance of practical courses with NASA astronauts on the ТДК-7СТ(2) integrated simulator.
2. Program for the training of NASA astronauts as part of a crew on the simulator for the integrated control of the transport vehicle during descent from orbit, for actions to take in off-nominal situations and for flight safety assurance ТДК-7СТ(2).
3. Program for the study of flight data file sections, of the flight program, and transport vehicle ballistics.

Summary of the Typical Training Program:

Table 7.6

Name of exercises	**Number of exercises/ number of hours**
Training for practical exercises with NASA astronauts	3 / 6
Practical exercises with NASA astronauts on integrated simulator	3 / 12
Training for training sessions as part of crew for integrated control of transport vehicle during descent from orbit	5 / 10
Training sessions as part of crew for integrated control of transport vehicle during descent from orbit	5 / 20
Study of flight data files, flight program, and transport vehicle ballistics (in class)	10 / 20
TOTAL:	68 hours

The NASA astronauts' readiness is verified by a board during the performance of a test training session on the transport vehicle integrated simulator for the performance of a descent as part of a crew and during a test concerning the flight program and transport vehicle ballistics within the framework of the typical training program.

Upon completion of the NASA astronauts' training program concerning the Soyuz TM transport vehicle for the NASA-*Mir* program, the following conclusions can be made on the basis of its analysis:

- On the whole, the scope and content of the exercises enables a NASA astronaut to be trained to execute, if necessary, a descent from orbit as part of the crew on the Soyuz TM transport vehicle in the seat of the cosmonaut/researcher.
- The replacement of Russian cosmonauts on the *Mir* station did not coincide with the replacement of NASA astronauts. Therefore, the American astronaut often flew with two different crews. But during training it was not always possible to conduct training sessions for descent with both one crew and with the other because their training times did not coincide.
- The effective and qualitative training of NASA astronauts during the initial stage was hampered by the poor knowledge that some of them had of the Russian language.

The given experience of NASA astronaut training for the NASA-*Mir* program needs to be taken into consideration during subsequent training for ISS:

1. It is possible to provide only minimum training if the duties on Soyuz are limited to those of a passenger.
2. It is best to perform NASA astronaut training sessions for descent from orbit on the Soyuz TM transport vehicle with all crews with which the possibility exists for executing a descent.
3. Before the beginning of Soyuz TM transport vehicle training the NASA astronaut should be proficient in the Russian language.

7.5 Training of Astronauts on *Mir* Orbital Complex Simulators and System Mockups

Russian-American crews were trained on *Mir* simulators and system mockups using the forms and methods used to train prior *Mir* crews. Training of a third crew member, the U.S. astronaut, as flight engineer-2, was the main difference in crew training in the *Mir*-NASA program.

The need to train an astronaut in the scope of flight engineer-2 duties arose as a result of analysis of participation in the operation of onboard systems and in the science program on board the *Mir* by Norm Thagard, as part of *Mir*-18 in the *Mir*-Shuttle program.

Training of NASA astronauts on *Mir* simulators and system mockups was conducted on the basis of the "Standard NASA Astronaut Training Program" No. E/5201, "Functions and Responsibilities of Astronauts and *Mir* Crew Members on Long-Term Missions," No. WG-5/NASA/GCTC/RSCE/5200, and science program Integrated Payload Requirements Document IPRD.

The NASA astronaut-training program called for individual practical classes (without participation of the entire crew) with astronauts on *Mir* simulators to develop the skills of operating the main onboard systems within the limits of flight engineer-2 functional duties. The purpose of these classes was to ensure a level of astronaut proficiency sufficient for training sessions as part of a crew.

The purpose of NASA astronaut training as part of a crew was to ensure *Mir* crew readiness to accomplish the entire mission on board the station and to take action in emergency and off-nominal situations. At this stage, in accordance with the scenario devised by the instructor, the crew as a single team would practice the basic elements of the mission program, including operation of several onboard systems and science hardware simultaneously, still-camera and video filming inside the *Mir* simulator, and conduct of radio and television communications with a simulated MCC.

Crew training on work organization on board the *Mir*, which in a number of cases causes problem situations associated with rescheduling of tasks and refreshment (acquisition) of the necessary knowledge and skills with onboard systems and science hardware even during execution of integrated modes (redocking, EVA preparation and conduct, transport-cargo vehicle remote operator mode and so forth) was the task of training sessions in integrated control of *Mir* onboard systems and science hardware.

In the process of crew training on *Mir* simulators, the required work style was developed, i.e. the totality of knowledge and skill necessary to perform the tasks of the mission program, as well as the ability to find optimal solutions in planning and organizing work on the *Mir*.

Additionally, much attention was paid in *Mir* crew training to questions of safety assurance, in particular to emergency evacuation of the complex in the event of emergency situations associated with depressurization or fire.

The NASA astronaut standard training program on the *Mir* simulators is shown below. Besides the practical classes and training sessions on the simulators, it also includes classroom sessions on flight data files (playing out of various flight situations from the flight data files), classes on ascertaining changes in *Mir* technical status, study of MCC functioning, and classes on the mission program.

Practical Classes and Classes on the Flight Data Files, *Mir* Technical Status, Structure and Functioning of GOGU Groups, and Mission Program

Table 7.7

№	Code	Class topic	Hours	Location	Notes
1	ПЗ-1	Developing practical skills in operating the СУБК and УИВК consoles	2	“Дон-17КС	Conducted with crew
2	ПЗ-2	Developing practical skills in operating the СУД and ОДУ onboard systems	2	“Дон-17КС	Conducted with crew
3	ПП-1	Technical status of *Mir* onboard systems and science hardware	2	class-room MCC	
4	ПП-2	Flight data files	2	class-room	Conducted with crew in preparation for session
5	ПП-3	Analysis of *Mir* mission progress	2	class, GCTC	
6	ПП-4	*Mir*-Shuttle joint procedures	2	class-room, GCTC	Jointly with STS crew
7	ПП-5	Mission program consultation	2	MCC	
		Total scheduled:	14		

Integrated Training Sessions

Table 7.8

№	Code	Class topic	Hours	Location	Notes
1	Тр-1	ПДС operation, experiments	6 (2+4)	"Дон-17КС	Only ПДС operation
2	Тр-2	ПДС operation, experiments	6 (2+4)	"Дон-17КС	Only ПДС operation
3	Тр-3	ПДС operation, experiments	6 (2+4)	"Дон-17КС	
4	Тр-4	ПДС operation, experiments, fire	6 (2+4)	"Дон-17КС+Т ДК-7СГ	as part of *Mir* No. – crew
5	Тр-5	СП-ЭО depressurization	6 (2+4)	"Дон-17КС"	
6	Тр-6	СП-ЭО depressurization	2	""ЭУ-734"	as part of *Mir* No. – crew
7	ТПС	standard flight days	10 (2+8)	"Дон-17КС"	as part of *Mir* No. – crew
8	ЭКТ	standard flight days	10 (2+8)	"Дон-17КС"	as part of *Mir* No. – crew
		Total scheduled:	52		

A board tests astronaut readiness during an examination session on the *Mir* integrated simulator ("Дон-17КС") upon execution of the standard flight day program and test on the mission program.

7.6 Conclusions and Proposals for the Overall Astronaut Training Program

1. Overall the scope and content of the classes made it possible to train the NASA astronaut as a flight engineer-2 in the *Mir* crew with the functions defined by document No. 5200.

2. Because the replacement of Russian cosmonauts on the *Mir* did not coincide with the replacement of NASA astronauts, during training it was not always possible to hold joint training sessions of the American astronaut with all the crews with whom he/she would fly in space. The result was that in some flights the crew commander, without knowing the actual proficiency level of the astronaut, did not always trust the astronaut to perform individual flight engineer-2 operations, even when the latter was adequately trained to do so.

3. During ISS crew training, joint training of all members of a specific ISS crew should be conducted as frequently as possible, especially in the crew training stage. This will improve the effectiveness of work on board the complex and help to resolve the problem of language training in dealings between crew members and with ground control personnel, gradually reducing the use of interpreters in the training process.

4. To train ISS crews it is necessary to maximally utilize already-developed forms and methods of training for the *Mir* complex.

5. In order to improve the training of ISS crews and improve the effectiveness of their work on board the station, it would be helpful to analyze the actions of ISS crews in the course of spaceflights and to use the results of analysis in training.

7.7 Training for Cosmonauts in the U.S.

The cosmonauts were trained to several levels based on their responsibilities: Full Mission Specialists, passenger only, visitors to the Shuttle during docked phase. Mission Specialist's duties varied but included the use of the Shuttle life-support systems and communications systems in nominal and selected off-nominal situations, payload activities, earth observations and photographic activities. For one mission, duties included use of the Shuttle's remote manipulator system, and on another flight, the cosmonaut conducted an EVA. Training related to egress and emergency egress was also provided to ensure the safety of the cosmonaut under all conditions.

For the cosmonauts that were being transported to *Mir*, the training was reduced and was primarily designed to keep the cosmonauts safe. This training also provided a general familiarity of the Shuttle life and crew support systems. Table 7.9 provides data on training hours for both the mission specialists' roles and the safety training only.

For the *Mir* crews that only visited the Shuttle while docked, the training focused on a general familiarity of the Shuttle life and crew support systems and transfer operations between Shuttle and *Mir*. In general this training averaged about 36 hours.

A portion of the payload training for the cosmonauts also occurred in the U.S. during the sessions according to the joint schedule.

COSMONAUT SHUTTLE TRAINING*

Table 7.9

	INT ASC	INT ENT	INT ORBIT	ORBIT	ASCENT/ENTRY	ORBIT SYSTEMS	CREW SYSTEMS	EVA	PDRS	PAYLOADS	RNDZ/PROX OPS	SPACELAB	SPACEHAB	REFRESHER	NEW ASTRO		TOTAL
Krikalev (Titov)	1	15	75	53	63	9	70	24	151	70	70	0	16	128	80		**825**
Titov**	17	30	162	117	178	10	103	137	75	28	34	0	46	74	11		**1022**
Kondakova	1	7	50	60	21	8	70	13	0	6	22	0	27	21	57		**363**
Sharipov	1	7	50	0	4	0	50	0	0	2	0	0	3	16	7		**140**
Ryumin	0	7	40	36	8	8	74	0	0	0	15	0	12	23	43		**266**
Dezhurov	0	0	7	0	4	8	12	0	0	0	0	1	0	26	11		**69**
Strekalov	0	0	7	0	4	0	12	0	0	0	0	2	0	25	13		**63**

Table 7.9 Cont.

	INT ASC	INT ENT	INT ORBIT	ORBIT	ASCENT/ENTRY	ORBIT SYSTEMS	CREW SYSTEMS	EVA	PDRS	PAYLOADS	RNDZ/PROX OPS	SPACELAB	SPACEHAB	REFRESHER	NEW ASTRO		TOTAL
Onufriyenko	0	0	7	9	4	0	50	0	0	2	0	2	0	29	19		**122**
Usachev	0	0	0	9	0	0	30	0	0	2	0	2	0	0	5		**48**
Budarin	0	0	7	9	8	0	61	0	0	2	0	2	0	25	15		**129**
Solovyev	0	0	12	9	4	0	49	0	0	2	0	2	0	3	17		**98**

*Table reflects only formal training. Hours may vary due to different degrees of initial preparation (workbooks) while still in Russia.
**2 flights (STS 63, 86)

7.8 Crew Training for Execution of the Science Program

7.8.1 Crew Training for Execution of the Scientific Investigations and Experiments

Training of crews participating in the *Mir*-NASA international program was a most important component of the successfully executed scientific investigations and experiments (ННиЭ) program. The quality of space vehicle crew training, as spaceflight experience demonstrates, greatly depends on the organization of training, on the level of science hardware training model availability, and on the timeliness of flight data file and training-procedure systems development, as well as on the proficiency level of instructors and teachers.

The order, scope, and content of training of Russian cosmonauts and American astronauts in the scientific program were decided in accordance with the concurred Organizational Coordination Plan of the sides to implement the *Mir*-NASA scientific program (US/R-001), the Integrated Payload Requirements Document (IPRD), and proposals made by both sides for each specific mission.

The work procedures for organization of crew training to conduct American experiments on the *Mir* called for preparation of a preliminary training plan by the American side based on information about the planned experiments, with development of a final work plan by Russian experts to make sure that American demands were met. Based on the experience of joint work in the *Mir*-Shuttle program, the following order of training organization was developed: Training in a joint science program for the mission began with a 3-week session conducted at JSC by JSC instructors, including basic training in the experiments and familiarization with science hardware. Subsequently training was conducted at the GCTC by GCTC instructors with the participation of representatives of all interested organizations. Six months before launch there was a second 3-week session at JSC, basically including practical training and meetings with the experiment suppliers. The final training stage in the science program was conducted at the GCTC using a concurred set of flight data files.

The work procedure also required that the American side deliver all documentation on experimental methods, along with the hardware used in crew training within the framework of the joint science program, to RSC-E and the GCTC. During crew training the GCTC instructors were guided by the dimensional installation drawings, electrical diagrams, development requirements and technical descriptions for the development of hardware (documents 100 and 101), as well as by existing flight data files and training-methods documents.

Experience acquired in implementation of long-term crewed flights testifies that effective execution of the science program is possible only when the crew members are active participants in the scientific investigations and experiments.

This in turn is achieved when in the training process the cosmonauts are not restricted to forming the skills of experiment algorithm execution, but acquire some fundamental knowledge about the studied phenomenon in the necessary scope, and become acquainted with the design principles of the science hardware, its design, and functioning.

In this regard, based on the content of the *Mir*-NASA science program, the following crew tasks and functions were defined during training planning:

- participation in preparatory operations (circuit assembly etc.) and execution of experiments and investigations in accordance with onboard instructions and procedures;
- recording of experiment results (including with onboard recording systems and hardware);
- operation, maintenance and repair tasks with the science hardware;
- storage and delivery to the ground of materials with the results of science experiments and investigations.

GCTC experts participated in concurrence of the science program, development of the experimental procedures, and correction of the flight data files (from the results of flight data files used in crew training).

In the process of crew theoretical and practical training at the GCTC, available integrated *Mir* simulators and models, specialized science hardware stands (operator workplaces), and science hardware training models were used.

Crew members and instructors from both sides participated in training sessions. In the initial stage of training sessions, experiment suppliers, hardware curators and flight data file librarians from both sides participated. Crew readiness to perform the scientific investigations and experiments program was determined from the results of graded training sessions.

In order to enhance the quality of training of American astronauts and Russian cosmonauts for experiments in the *Mir*-NASA joint program, the following training hardware was transferred to the GCTC:

1. MIM – vibration-insulated platform;
2. TEM – MIM technological assessment;
3. QUELD II – electric oven;
4. PUP-A and PUB-B power distribution panels;
5. BTS – biotechnical system
6. CHAPAT – active telescope;
7. MGBx – glove box;
8. CFM (MGBx) – candle flame under microgravity conditions;
9. FFFT (MGBx) – flame propagation in gas stream;
10. ICE (MGBx) – interface surface investigation;
11. Dewar flask – protein crystallization;
12. EDLS – improved load sensors;
13. Canon A1 video camera with supplemental attachments;

14. Hasselblad camera;
15. TEPC – tissue-equivalent proportional counter;
16. SAMS – measurement of micro-accelerations in space;
17. SPSR – portable spectro-reflectometer for space conditions;
18. DCAM – diffusion-monitored protein crystallization;
19. BCAT – test of binary colloidal alloys

GCTC experts participated in acceptance tests (ПСИ) of science hardware simulators in order to study the submitted hardware, check conformity of flight and simulator models and develop experimental procedures.

During training, experts of GCTC and other organizations developed and utilized simulator models for science experiments, simulators of crew automated workplaces, and specialized databases, and a number of modern technologies were introduced.

In addition the GCTC performed a number of tasks to improve the training laboratory facilities in all scientific disciplines of the program. For these purposes:

1. They developed a laboratory for training in technical experiments (k. 106-3 and k.107-3). The laboratory includes:

- a working technical model of the Optizon-1 TX unit (the unit is used to perform an American experiment in liquid-phase sintering (LPS);
- maintenance systems;
- video monitoring system.

2. A laboratory was developed for training cosmonauts to perform biotechnical and biological experiments (k. 313-КМУ). The laboratory includes:

- the "Inkubator" science hardware training system;
- the "Oranzhereya-Svet" science hardware training system, which is installed and connected for training sessions to the "Kristall" module simulator;
- a hardware system support of cosmonaut training.

3. American hardware was installed, connected and stored for k.313-КМУ and k.225-2 (cosmonaut training laboratory for astrophysical and technical experiments) and k.208-2 (cosmonaut training laboratory for geophysical experiments).

4. Power distribution console PUP-B was connected to a 27 V power system in k.225-2.

5. Experimental procedures developed.

6. Experiment onboard instructions developed.

7. Repair and checkouts of technical model of Optizon-1 TX unit and its control system "Oniks" (malfunction occurred during joint development with American experts of a procedure for conducting the LPS experiment).

To study the procedures and acquire practical skills the following workplaces were developed in specialized laboratories:

1. To conduct the BTS experiment, study of possibility and effectiveness of growing various bio-objects under microgravity conditions.

Hardware:

BTS – biotechnical system;
PUP-A and PUP-B – power distribution consoles;
MIPS-2 – "Lepton" computer and controller.

2. To conduct the experiment with the Dewar flask hardware. Growth of protein monocrystals.

Hardware:

Dewar flask;
Canon A1 video camera with attachments.

3. To conduct an experiment with the "Inkubator" hardware system. Studying the influence of spaceflight on development of Japanese quail embryos.

Hardware:

"Inkubator" hardware system;
power supply.

4. On the "Kristall" module simulator, for an experiment with the "Oranzhereya-Svet" hardware system. Study of plant growth under microgravity conditions and determination of the influence of spaceflight on plant life cycles.

Hardware:

"Oranzhereya-Svet" hardware system;
camera;
MIPS-2 – "Lepton" computer and controller.

5. To conduct the MIM experiment. Provision of insulation from vibrations under microgravity conditions and creation of forced vibration.

Hardware:

MIM hardware:
MIPS-2 – "Lepton computer and controller;
PUP-A and PUB-B power distribution panels;
double container.

6. To conduct TEM experiment. Study of MIM hardware properties with regard to its capacity to ensure vibration insulation under microgravity conditions.

Hardware:

MIM hardware:
MIPS-2 – "Lepton computer and controller;
PUP-A and PUB-B power distribution panels;
double container.

7. To conduct the QUELD II experiment. Measurement of diffusion coefficients for certain bimetal systems under microgravity conditions.

Hardware:

QUELD II hardware;
MIM hardware:
MIPS-2 – "Lepton computer and controller;
PUP-A and PUB-B power distribution panels;
double container.

8. To conduct CFM experiment. Study of candle diffusion flame under microgravity conditions.

Hardware:

CFM hardware;
GBx hardware (glove box);
power supply.

9. To conduct FFFT experiment. Study of forced combustion propagation under microgravity conditions.

Hardware:
FFFT hardware;
GBx hardware (glove box);
power supply.

10. To conduct ICE experiment: Study of equilibrium forms which are assumed by a liquid surface under microgravity conditions. Study of "liquid-vapor" interface dynamics.

Hardware:

ICE hardware;
MGBx hardware (glove box);
power supply.

11. To conduct the EDLS experiment: Measurement of normal forces and torque's caused by crew members during nominal activity on board the *Mir*.

Hardware:

EDLS hardware;
MIPS-2 – "Lepton computer and controller;
PUP-A and PUB-B power distribution panels.

12. To conduct the LPS experiment: High-temperature liquid-phase sintering. Study of defect formation in sintering products: Analysis of wetting and formation of alloys.

Hardware:

"Optizon-1" hardware.
Servicing hardware set;
Canon A1 video camera with attachments.

7.8.2 Crew Training to Conduct the Medical Section of the Science Program

Successful accomplishment of medical and specifically biomedical experiments is not possible without careful study of working techniques and methods on the part of cosmonauts and astronauts in preparation for drawing blood, taking biological materials samples, and processing samples.

In the first stage cosmonauts and astronauts were trained in the method of drawing blood from a vein.

The first familiarization class was conducted by NASA in the U.S.

During the class the crew members were taught:

- how to find and isolate the major vessels;
- sterile treatment;
- procedures for drawing blood from a vein with a "Butterfly," a disposable needle with vacuum container;
- procedures for drawing blood from a vein with a catheter.

It should be noted that crew members were interested in the training material and actively participated in the practical development of blood-drawing skills.

Before the start of the practical classes, crew members were shown video materials which detailed the requirements of the World Health Organization for medical personnel regarding compliance with safety procedures with working with biological material.

For practical development of these techniques, cosmonauts and astronauts were asked to draw blood from 4 volunteers. This procedure allows the cosmonauts to quickly acquire the techniques for drawing blood from a vein.

As early as the fourth or fifth class, cosmonauts could independently draw blood from a vein. In the training process, instructors paid special attention to possible complications associated with blood-drawing procedures and the methods to prevent them.

In our opinion, the procedure of drawing blood with a catheter posed the greatest difficulty, but by the end of the first session all crew members could independently draw blood with a catheter.

Experienced medium-level medical personnel taught the classes. However it should be noted that at this stage the training was conducted in a "free" manner. American instructors did not strictly adhere to the flight data file, because at the start of the session it had not been fully developed.

At the GCTC the Russian instructors were faced with a simple but important task: to maintain the acquired skill of drawing blood from a vein. This goal was achieved through regular practical classes. At this stage the cosmonauts performed all procedures strictly per the flight data file. The basic drawback of the classes was the extremely low number of volunteers for blood drawing. As a rule associates of the Mission Medical Control Center responsible for this stage of training came to the class site in low numbers (one or two) or not at all. In most cases blood drawing was practiced on the GCTC physician-instructor and the NASA flight surgeon.

To enhance the quality of training of American astronauts and Russian cosmonauts, the following training hardware was delivered to the GCTC for performing experiments in the *Mir*-NASA joint program.

1. Blood drawing system;
2. Blood drawing system;
3. Blood drawing system;
4. Isotopic marker kit;
5. Antigen kit;
6. Blood sample analyzer;

7. Bar-code reader;
8. Pharmacokinetic system;
9. TEAK magnetic data recorder;
10. Blood pressure continuous monitoring system;
11. Cardiomonitor;
12. Cardiology kit;
13. Postural examination system;
14. Surface sampling kit;
15. Formaldehyde monitor;
16. Sorption air sampler;
17. Air sample container;
18. Lido hardware;
19. Laboratory hardware;
20. Laboratory accessories;
21. Postural equilibrium platform;
22. Bicycle ergometer;
23. Electric power system;
24. Gaze experiment hardware;
25. Locomotion experiment hardware;
26. Metabolism hardware
27. "Sleep" experiment hardware;
28. "Coordination" experiment hardware.

Laboratories were developed for training cosmonauts to conduct the medical program. These included simulator systems and workplaces for the following fields:

1. Evaluation of skeletal muscle work ("Rabota");
2. Morphological, gastrochemical and ultrastructural characteristics of skeletal muscles ("Myshtsa");
3. Gaze and head coordination ("Vzor");
4. Sensory perception characteristics ("Orientastiya")
5. Locomotive integration paths ("Orientastiya");
6. "Expectant pose";
7. Monitoring postural equilibrium ("Ravnovesiye");
8. Motion biomechanics during locomotion ("Lokomotsiya");
9. Surface microbiological analysis;
10. Water microbiological analysis;
11. Water chemical analysis;
12. Air chemical analysis;
13. Investigation of onboard radiation situation;
14. Homeostasis of fluid and electrolyte and its regulation ("Gomeostaz");
15. Calcium metabolism dynamics and bone tissue;
16. Kidney stone formation risk evaluation;
17. Protein metabolism ("Belok");
18. Energy utilization ("Energia");
19. Metabolic reaction to physical loads;
20. Erythrocyte metabolism ("Eritrotsit");
21. Erythrocyte mass and survival

22. Pharmacokinetic changes ("Farmakokinetika");
23. Humoral immunity ("Gumor");
24. Virus reaction ("Virus");
25. Peripheral blood mononuclear cells;
26. Investigation of orthostatic stability using low-body negative pressure;
27. Investigation of orthostatic instability using ambulatory monitoring systems, check of baroreflector reflexes and Valsalda test ("Barorefleks");
28. Determination of aerobic work capacity by means of dosed bicycle ergometry ("Stupenchata veloergometriya");
29. Evaluation of temperature regulation during spaceflight ("Submaksimalnaya veloergometriya")

7.8.3 Conclusions, Notes, and Suggestions

1. The adopted work procedures for organizing crew training, existing and specially developed technical and training methods resources, as well as the proficiency of GCTC instructors, made it possible to provide timely and high-quality training of Russian cosmonauts and American astronauts to perform a whole group of science experiments and investigations in the *Mir*-NASA program. At the same time the inadequate supply of science hardware training models at the GCTC should be noted. Instead of equipping them with science hardware simulators (on the "Spektr" and "Priroda" module simulators), it was necessary to supply modules only with face panels or photographs of the science hardware.

2. During planning sessions for science program training, it is necessary to provide for mandatory delivery of science hardware training samples to Russia. It is necessary to concur with the GCTC on the number and type of manufactured equipment intended for crew training. During crew training, classes were held in two 3- or 4-week sessions in the U.S. In the period of yearlong crew training, science hardware training models were practically non-existent at the GCTC. This disrupted the continuity of the training process and prevents classes during the integrated training sessions on the *Mir* simulator before the start of the mission. It must become our practice not to clear science hardware training models for crew training if it has not undergone acceptance testing, if it has no safety certificate, and if it has not been concurred on in documents with GCTC experts on the question of degree of simulation of science hardware flight sets.

3. Experience has been accumulated in planning, organization, and conduct of cosmonaut and astronaut training in joint international science programs. This training must be carried out in the form of training sessions, in the process of which direct interaction of cosmonauts, astronauts, and Russian experts with the experiment suppliers and hardware developers is possible. In the organizational context, it is necessary to reduce the time between the final crew training session for the science program and the launch of the crews (in the process of *Mir*-NASA program implementation, these intervals could reach 6 months).

4. In order to enhance the quality of cosmonaut and astronaut training for the scientific program of experiments and investigations, it is necessary to constantly adjust the training process with allowance for experiment results of prior missions. To do this, it is necessary to have movie materials and brief reports of the science experiment suppliers at the GCTC regarding the results of the experiments.

5. Untimely delivery to the GCTC of flight data files regulating the distribution of responsibilities, the content, procedure and sequence of execution of operations by crew members hampered the training. In virtually all training for the *Mir*-NASA program, classes were held per intermediate versions of the flight data files and unapproved experiment procedures.

6. For a number of experiments, no Russian cosmonaut participation was planned, with the result that no cosmonaut training was planned, even though they had to participate in practically all experiments or in science hardware repair tasks.

7.9 NASA Astronaut Training for the *Mir* EVA Program

In the process of the *Mir*-NASA science program, there were plans for three EVAs by the NASA astronauts in Russian-American *Mir* crews. Data on these EVAs are provided in table 7.10.

EVAs by NASA Astronauts in Russian American *Mir* Crews

Table 7.10

№	EVA Crew	Basic Tasks
1	V.V. Tsibliev J. Linenger (*Mir*-23)	Installation of optical properties monitors (OPM) on the DM. Installation of Benton dosimeter on the "Kvant-2" instrument science compartment (ПНО). Removal of PIE and MSRE science hardware from the docking ring (ШСО).
2	A.Ya. Solovyev M. Foale (*Mir*-24)	Inspection of depressurized "Spektr" module. Inspection of exterior cold radiator panel (НХР). Measurement of annular gap around the СБ-2 drive using a special gauge. Securing of stowage to handrails in "Miras" science hardware on science/cargo module (НГО). Rotation of ДСБ-4 and СБ-4 (solar arrays) Removal of Benton dosimeter science hardware from "Kvant-2" module instrument science compartment.
3	A.Ya. Solovyev D. Wolf (*Mir*-24)	Egress from science instrument compartment. Inspection of egress hatch. Measurement with SPSR instrument on exterior surface of pressurized instrumentation module 1 (ПГО-1). TV report on first EVA – D. Wolf. Closure of egress hatch on main and supplemental locks. Check of docking ring pressure integrity.

In the period from 6/10/96 to 6/28/96, 7 theoretical and practical classes (dry) and 5 sessions in the pool in "Orlan-DMA-GN" space suits were conducted on standard EVA operations with NASA astronauts J. Linenger and M. Foale.

Training of NASA astronauts J. Linenger and M. Foale in the EVA program was conducted in items "ORLAN-DMA-GN" numbers 19 and 20 and "ORLAN-M-GN numbers 7 and 8 on *Mir* mockups (DM, "Spektr" and core module mockups), using dimensional-mass and mechanically operating mockups of hardware and EVA systems.

Two training sessions each under pool conditions and two practical classes were held on EVA target tasks—installation of the OPM instrument on the DM and of the Benton dosimeter on the Kvant-2 module, and removal of the PIE and MSRE instruments.

Ground training of M. Foale for an unplanned EVA on 9/6/97 to inspect the exterior surface of the depressurized "Spektr" module was not held.

As a result of the training of the Russian-American EVA crew, operators consisting of Tsibliyev and Linenger (main crew) and Budarin and Foale (backup crew):

- acquired practical skills in installation of the OPM instrument on the DM and of the Benton dosimeter on the Kvant-2 module, and removal of the PIE and MSRE instruments;

- practiced elements of the EVA timeline in accordance with the flight data files;

- practiced actions in contingency off-nominal situations in accordance with the flight data files.

Training of NASA astronauts David Wolf and Andrew Thomas in the EVA program was conducted under conditions of modeled weightlessness in the pool and short-term weightlessness in the flying laboratory IL-76MDK.

Training for EVA under modeled weightlessness conditions in the pool was conducted on the *Mir* mockups (core module, Spektr, docking ring, DM) using the dimension-mass and mechanical operating mockups for SPSR and OPM in scuba gear, and in space suits "ORLAN-DMA-GN" No. 20 and "ORLAN-M-GN" No. 8. Scuba training of NASA astronauts was not conducted since the trainees already had scuba certificates.

When the scope of training for NASA astronaut David Wolf was determined, allowance was made for his prior experience in working in the EMU space suit at the JSC hydrolab. In addition, the conduct of standard EVA operations in scuba gear made it possible to reduce the total number of submersions of NASA astronaut David Wolf in the "Orlan-DMA(M)-GN" space suits.

In the process of training in standard EVA operations, the "Orlan-DMA(M)-GN" space suit, as well as the EVA program and procedures for measurement with the SPSR instrument, D. Wolf and A. Thomas had 3 practical classes each (10 hours).

D. Wolf and A. Thomas performed 4 checkout submersions in scuba gear and practical training in scuba gear for standard EVA operations (16 hours). In practicing the standard EVA operations in the EVA program (OPM removal and working with the SPSR), D. Wolf was submerged 4 times (16 hours) in the "Orlan-DMA(M)-GN" space suits. Learning the practical skills of donning and removing the space suit "Sokol-KV-2" and "Orlan-DMA-VL" flight modes, as well as working in these space suits in weightlessness under short-term weightless conditions on the flying laboratory IL-76MDK, D. Wolf and A. Thomas performed 1 flight (4 hours).

As a result of training under modeled weightless conditions in the pool and short-term weightlessness on the flying laboratory, NASA astronaut D. Wolf acquired:

- theoretical knowledge and practical skills in working in scuba gear;
- theoretical knowledge and practical skills in donning and removing the "Sokol-KV-2" space suit, the "Orlan-DMA-VL" space suit, and the "Orlan-DMA(M)-GN" space suit, as well as working in these space suits;
- practical skills in removing the OPM and working (measurement procedures) with the SPSR spectro-reflectometer.

NASA astronaut David Wolf acquired the skills of:

- standard EVA operations in scuba gear and in the "Orlan-DMA(M)-GN" space suit;
- EVA timeline elements in accordance with the flight data files;
- actions in contingency off-nominal situations.

As a result of training under conditions of modeled weightlessness in the pool and short-term weightlessness on the flying laboratory, NASA astronaut Andrew Thomas acquired:

- theoretical knowledge and practical skills of working in scuba gear;
- theoretical knowledge and practical skills in donning and removing the "Sokol-KV-2" space suit, the "Orlan-DMA-VL" space suit, and the "Orlan-DMA(M)-GN" space suit, as well as working in these space suits.

Training of NASA astronauts A. Thomas and J. Voss in the EVA program was conducted in the period from September 30, 1997 to November 30, 1997.

Training sessions were conducted in the space suits "ORLAND-DMA-GN" numbers 21 and 22 and space suits "ORLAN-M-GN" numbers 7 and 8. The training process utilized:

- the core module mockup;
- instrument science compartment mockup;
- special airlock mockup;
- Kvant module mockup;
- cargo boom on service stand;
- OPM science hardware dimensional mockup;
- SPSR science hardware dimensional mockup;
- "Truss-3" dimensional mockup;
- "Sofor" truss dimensional mockup;
- "Sofor" trust installation ring (KM);
- *Mir* orbital complex training mockup (1:20);
- EVA tool kit

Scuba training of the NASA astronauts was not conducted since the trainees had their scuba certificates.

When the scope of training of NASA astronauts Andrew Thomas and James Voss was decided, allowance was made for their prior experience in working in the EMU space suit at the JSC hydrolab.

The total number of submersions of NASA astronauts Andrew Thomas and James Voss in the "Orlan-DMA(M)-GN" space suits was reduced owning to earlier practice in standard EVA operations in the process of scuba training.

When the number and duration of theoretical and practical classes of NASA astronaut Andrew Thomas were determined, allowance was made for his training as part of NASA-6.

Practice of standard EVA tasks in space suits was conducted in the process of astronaut training in standard EVA timelines.

In the process of training, the following were conducted with A. Thomas and J. Voss:

- theoretical and practical training in the EVA program (standard operations, terminology, tasks, training resources, science hardware), with A. Thomas 9 classes (13 hours), with J. Voss 10 classes (16 hours);
- practical training in scuba gear СВУ-3: A. Thomas did 3 training sessions (9 hours), while J. Voss did 4 training sessions (12 hours);
- in the "Orlan-DMA(M)-GN)" space suit, A. Thomas and J. Voss did 4 training sessions each (16 hours).

As a result of training for EVA on the *Mir* orbital complex, NASA-7 astronauts Andrew Thomas and James Voss acquired skills in performance of:

- standard EVA operations in scuba gear and in the "Orlan-DMA(M)-GN" space suit;
- standard EVA timelines in accordance with the flight data files;

- actions in contingent off-nominal situations.

In conclusion, the scope and content of training of the 4 NASA astronauts in the EVA program on the *Mir* were adequate for successful accomplishment of the program of 3 EVAs.

7.10 Summary of *Mir*-NASA Crew Training

The *Mir*-NASA joint flight program allowed the GCTC to accumulate considerable experience in training Russian-American crews. The GCTC trained American astronauts:

- on the transport vehicle: as cosmonaut-researcher in the transport vehicle descent stage (if emergency evacuation of the *Mir* was required);
- on the *Mir* orbital complex: as the flight engineer for individual systems of the *Mir* long-term mission;
- on EVAs jointly with the Russian cosmonaut in order to accomplish the science program, inspect the *Mir* and restore its functionality;
- on the joint science program at the GCTC and the JSC. Experience was acquired in medical certification and flight clearance of cosmonauts and astronauts.

The *Mir*-NASA joint flight program made it possible to accumulate considerable experience in the general work of interaction of the Russian-American space crews and experts.

The Russian Space Agency and NASA experts had an opportunity to become acquainted with one another, with the space centers of the partners, and with the system and specifics of training cosmonauts for spaceflights in Russia and in the U.S. The joint work furthered mutual improvements and development of common approaches to cosmonaut training, planning and implementation of space missions and measures associated with them. Cooperation in space by the Russian and American sides made it possible to approach the next stage in the conquest of space — the uniting of efforts to develop the ISSand to train the crews for its assembly and operation.

Astronaut Scott Parazynski performs an EVA during STS-86

Section 8 - Extravehicular Activity (EVA)

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8.1 Executive Summary

For decades, the U.S. and Russia evolved independent space programs. Many of us were always curious about what our counterparts were accomplishing and if we could learn anything from each other. Tentative informal contacts have blossomed through the Phase 1 program to the point where strong mutual understanding now exists. We have found more common ground on a wide range of topics than differences. We built a strong foundation for future International Space Station (ISS) efforts in the course of accomplishing useful work. The individual missions, hardware and operations were tools in this work. Above all, we know the people and processes which will carry us forward.

For external tasks, the means of accomplishing these mutual efforts was the joint EVA WG. This group was chartered in September 1994 with responsibilities for the safe and successful development of all *Mir*-NASA EVA requirements and much of their implementation. It included representatives from all the key U.S. and Russian organizations. From hardware development to crew training and real-time Mission Control Center (MCC) support, this group led the charge on all joint EVA ventures. Interaction and support involving all of the other joint WGs was essential to overall success, since EVA is not and cannot ever be accomplished by a single discipline.

This report highlights the primary accomplishments, lessons learned and processes which are felt to have been of most importance. For most cases, the lessons are merely reinforcements of ideas we hopefully already knew independently. Now that we have a better common understanding of each other, together we realize that we have the potential to be stronger and more capable with our combined resources than if we go it alone. The trick is finding the path which uses each other's strengths.

8.2 Structures/Processes/Relationships

From the start, the joint EVA WG has relied upon the positive characteristics of the people involved. On both sides, each participant brought a high level of experience to bear on all issues. Each side shares a common desire for crew and task safety/success as well as a sense of the importance of each spacewalk to the perceived overall readiness to the long-term future. All exhibited a strong dose of common sense and trust in approaching each problem. Patience was the essential virtue to finding common understanding and solutions. In resolving each objective, motivations and physics tended to be universal rather than unique.

As with most projects, early and continuous participation of experienced team members is essential. Initial solution concepts evolve over time for many reasons. With numerous parallel projects occurring at the same time and limited manpower, plowing up old ground is not efficient (though sometimes valid as a sanity check). Even so, for the sustained long-term health of all, new personnel and ideas must be injected periodically. For joint efforts, it is best if personnel start out knowing the fundamentals and grow over time. Hands-on or suited trial and error learning opportunities with real hardware and facilities benefit everyone because paper level engineering is only as good as the experience of the participants. Attention to training skilled personnel is just as important to ground activities as it is to on-orbit operations.

To avoid reinventing the wheel and repeating past mistakes, knowing a certain amount of history is invaluable. Too many times, we have a tendency to focus so hard on current and future issues and not take advantage of past successes. New solutions balanced with consideration of existing hardware designs and experience can be faster, better, and cheaper. The EVA group spent considerable time exchanging records of past on-orbit statistics and task accomplishments. This historical information often expedited and helped validate solutions which would otherwise have been more difficult and had higher perceived risk.

As with most ventures, the start-up can be the most painful and time critical period. Team building and familiarity with each other's organizational hierarchy really enhance this transition. A clear understanding of personal and institutional responsibilities is also essential. Work and social time must go hand in hand so each learns interpersonal and organizational handling skills. People and cultural skills are critical to joint efforts. Being able to walk in the shoes of others is an old but true cliché. Overseas survival skills were learned that can be built upon. Things normally taken for granted like business services, facility access, transportation, food, health services, and entertainment may still need improvement, but the essentials do exist and are practically obtainable. These details make all the rest of the joint activities livable and more sustainable.

Advance planning and well-thought-out conceptual solutions are fundamentals, the importance of which cannot be understated. A weak up-front understanding of the problems and the pros/cons of each alternative can lead to a late realization of major painful changes. Margin in schedules, redundancy, and physical parameters cannot be overemphasized. Like a game of chess, more steps worked through in advance and more contingency plans in your pocket lead to victory. Proactive anticipation of issues allows maximum response time. Afterwards, attention to detail and constantly searching for weaknesses is important, but overall, a good end product starts with a good idea.

Coordinated implementation of each problem solution has to be facilitated by a variety of communication methods. Considering the long distance and time differential between Moscow and Houston, each communication opportunity is precious. Each agreement has to be clear, fully understood and well distributed. Face-to-face meetings and teleconferences have been the primary means of exchanging information. Agreements are recorded in protocols, faxes, drawings, electronic mail and formal documents. Without these and other information exchange alternatives, no productive work can be accomplished. Even so, periodic progress reviews and each side's coordination and enforcement of joint agreements are most critical to the quality and timeliness of implementation efforts.

A multidiscipline and multilevel participation approach also aided our joint efforts. We worked from the bottom up and the top down (especially when time was short). Driving assumptions toward zero was accomplished by coordinating with hardware designers, manufacturers, technicians, training organizations, crew members and management to confirm that all were headed in the same direction. Since late surprises are hard to recover from, more widespread involvement and regular peer review aids implementation and acceptance of the end solution (though it can also slow things down if not carefully managed).

Mutual time management was enhanced by Phase 1 involvement. Real schedules and templates of generic processes were exercised and understood that apply to ISS. From hardware development to crew training flows and on-orbit timelines, we have a good grasp of realistic milestones and durations for implementing various future activities.

One of the real strengths of the joint EVA WG, relative to some of the other joint groups, was that participants on both sides supported both Phase 1 and ISS work simultaneously. For us, there was no real distinction and the lessons learned in one program fed directly into the other. This accelerated our understanding of issues and solutions. In summary, the EVA WG, which participated in both programs, became much stronger as a result.

8.3 Certificate of Flight Readiness (COFR) Process

The COFR process related to EVA evolved over time during the *Mir*-NASA program. As with past well-rehearsed Shuttle missions, it addresses readiness of the people, operations and hardware prior to launch. During *Mir*, it also adapted to address unanticipated tasks/training. Feasibility and safety reviews were held for new operations before allowing on-orbit training or external activities. Future joint reviews will continue to emphasize early data exchange to avoid last minute "just-in-time" assessments. This extension of past Shuttle-style real-time planning and implementation reviews can be used for ISS events.

8.4 Training

Additional details on EVA training are further discussed in Section 7.

8.5 Accomplishments

1. STS-71 96 Bolts and Capture Latches - If the Shuttle and ISS fail to undock normally, the ultimate failure response calls for EVA release. Safely separating two massive objects without a major redesign of either vehicle was successfully developed before the first *Mir* docking. The same tools/techniques will be available for all ISS missions.

2. STS-71/*Mir*-18 Spektr Solar Array Cutter - After Spektr docked with *Mir*, one of its fishtail arrays failed to deploy normally. EVA was requested to develop a solution to improve available power for *Mir* systems and science. NASA and RSC-Energia (RSC-E) each manufactured, certified, and delivered candidate cutting tools in a matter of days. Using a small experienced team and adapting off-the-shelf parts, NASA's tool was ultimately used by the *Mir* crew to free the array. Similar tools/techniques will be available on ISS and can be utilized if needed again. This joint demonstration of rapid information exchange and accelerated tool development is a positive example of successful response to ISS assembly and maintenance failures.

3. STS-74 Docking Module (DM) and Solar Arrays - Design development and verification of the flight DM, its external solar arrays and water tank mockups of both served as an early example of the future for ISS. Joint requirements and inspection methods utilized for this *Mir* module have been migrated into use with ISS modules. Many design features have 1:1 correlation with ISS. The mockup implementation taught concrete lessons for the future. The benefit of start-to-finish experience with real hardware is invaluable.

4. *Mir*-21 Particle Impact Experiment (PIE) and *Mir* Sample Return Equipment (MSRE) - The first "joint" EVA called for *Mir* cosmonauts to deploy external U.S. science experiments. The up-front design of packaging, handling, locating, and attaching these items taught many of the fundamentals of *Mir*/ISS EVA integration and operations. NASA had not worked with similar science equipment since Skylab, so the extensive Russian experience in this realm was essential.

5. STS-76 Docked EVA (*Mir* Environmental Effects Payload [MEEP], Camera, Tethers/Foot Restraint) - The second "joint" EVA was not much different than most past Shuttle EVAs. It was, however, the first example of how the U.S. will perform EVA while docked and how to safely maneuver and restrain crew and equipment along ISS-type vehicles. Tasks included the deployment of 4 passive MEEP material science experiments, retrieval of a video camera for future reuse and evaluation of jointly designed tethers and foot restraints.

6. *Mir*-23 Joint EVA (Optical Properties Monitor [OPM], PIE, MSRE, Benton) - The next "joint" EVA was the first one to mix astronauts and cosmonauts outside in Orlan suits. Between preflight development, crew training and on-orbit work, most of the fundamental processes and techniques of Russian EVA were jointly exercised. While the experience with external science was important, the real benefit came from detailed understanding of generic EVA implementation.

7. STS-86 Joint Docked EVA (MEEP, Tethers/Foot Restraint, Simplified Aid for EVA Rescue [SAFER]) - To round out our joint experience, this EVA again mixed astronauts and cosmonauts, but in NASA extravehicular mobility units (EMUs). Besides retrieving the MEEP experiments, it yielded final experience with new EVA support equipment and utilization techniques prior to ISS implementation.

8. STS-86/*Mir*-24 Spektr Repair Hardware - Another example of rapid response to on-orbit problems is exemplified by the Spektr leak repair equipment delivered to

Mir by STS-86. Joint efforts included late training of the Shuttle EVA crew to transfer a large sealing cap from the cabin interior to the DM exterior for later use by *Mir* cosmonauts. Information exchanged on the devices and materials involved in finding and fixing module pressure shell leaks was mutually beneficial for ISS.

9. *Mir*-24 Spektr interior EVA - To restore power from the depressurized Spektr module, precedent setting internal work was planned, hardware was delivered to *Mir* and the tasks were safely implemented. Techniques of working internally in small volumes with poor lighting while anticipating and avoiding hazards were rapidly refined from past experiences. As another example for the future, the adaptability of basic EVA capability was proven in reaction to unanticipated hardware and situations.

10. *Mir*-24 Joint EVA (Spektr inspection, on-orbit training, Benton) - In the midst of a difficult period for all involved with *Mir*, the opportunity was made for more intense and first-hand joint experience in inspecting and diagnosing significant and widespread vehicle damage. Again, a mixed EVA crew of one astronaut and one cosmonaut was utilized for maximum mutual experience. This again showed the feasibility of building upon basic skills/experience via on-orbit training to safely react to unforeseen events and unquantified external conditions.

11. *Mir*-25 Joint EVA (preflight training, on-orbit training, space portable spectral reflectometer [SPSR]) - This was the third and last time a U.S. astronaut conducted EVA on *Mir*. Despite the extra challenge induced by a malfunctioning external hatch which altered the nominal egress/ingress procedures, the work was safely completed. The combination of all preflight and on-orbit experiences built a strong foundation for these on-orbit efforts.

12. STS-91/*Mir*-25 hardware transfer/return - The return of previously delivered, used and stored EVA hardware was a successful example of early coordination between past crew members and ground personnel. Clearly communicating where to look and what to look for was implemented by making sure everyone involved in MCC-M, on-orbit and in postflight processing had the same equipment information. The pre-pack effort was facilitated by starting early, consulting the memories of past cosmonauts, and getting photos and part numbers to all in MCC and on orbit.

13. Interoperable hardware - One of the big goals implemented and validated during Phase 1 was the development of hardware for shared use by both Orlan and EMU suited crew. Simple suit components like radiation dosimeters, moleskin abrasion protection, helmet visor antifog and personal hygiene underwear were jointly certified and used. Universal foot restraints, tether hooks, safety tethers and tool/body restraint tethers were proven and are being carried over for ISS.

14. Energy Module - The energy module was to be a Shuttle-delivered solar dynamics demonstration project that was ultimately canceled, but before that time,

it reached the critical design stage. EVA participation in its development had a direct benefit as a joint learning experience. This large complex hardware not only needed EVA crew for assembly, contingencies, and maintenance, but it would have required direct interaction between EVA crew and a robotic manipulator. It also helped us address "what-if" questions related to simultaneous operations with 2 EMU and 2 Orlan suited crew members. Except for the 4-person scenario, many of the operational EVA and robotic concepts and some of the interface hardware will be reused for the ISS 9A.1 SPP.

8.6 Lessons Learned

To do any productive joint work, you have to have at least a basic understanding of each other's capabilities, strengths, and weaknesses. Knowledge of each other's suits, airlocks, tools, facilities, vehicle interfaces and operational techniques is crucial to finding common solutions. Independent of differences like quantity of available documentation, we found no fundamental technical difficulties precluding joint cooperation. For example, the EMU and Orlan are both adequate to do productive work when properly used within design parameters. This flexibility will be utilized to optimize and balance the work wherever it may be needed on ISS.

On-Orbit Training

Since an infinite level of pre-mission planning cannot anticipate all on-orbit contingencies and keep the crew proficient forever, the means of adapting to off-nominal situations is extremely important. Together we confirmed that the ground and on-orbit crew must have rapid, identical and detailed data on the hardware and operations for vehicle, airlock, suit and tool interfaces (CD-ROMS, scale models, procedures, videos, photos, etc.). Quality time spent coordinating subtle implementation details between the ground teams and each member of the flight crew must not be excluded. The crew members must further work out roles and responsibilities among themselves by pre-EVA choreography of each step of nominal and off-nominal procedures. In-cabin practice with the suits, tools and worksite mockups helps all confirm EVA readiness for almost any situation.

Intravehicular Activity (IVA) Crew Support of EVA

Each of the *Mir* astronauts supported a number of EVAs performed by Russian cosmonauts. This included operating the *Mir* as well as, for example, controlling the deployment of the solar arrays. This support was essential to successful EVA completion. It also served as a reminder that IVA crew readiness to aid external work can only be accomplished with preparation/training and an adequate understanding of essential vehicle systems.

MCC-M, MCC-H and Station Operations

All other activities are sometimes secondary to what happens during real-time interactions between the crew and ground control teams. Quickly responding to problems and questions relies on all past knowledge and experience with a measure of creative responsiveness. Each side gained first-hand practice in the methods and limitations of each other's air-to-ground voice, telemetry and email communication capabilities. Failure analysis and root cause information sharing was demonstrated. It was reinforced that EVA is just a part of the total operations of a station and that external task workload must suit the overall mission objectives of IVA science, maintenance, cargo transfer, crew handovers, and basic living.

Organizational Responsibilities

In the dynamic organizational environment leading into ISS, all are relearning their roles and responsibilities. JSC institutional groups, which did not fully embrace Phase 1 efforts early on, have now realized that their support for ISS cannot be restricted to U.S. boundaries. A reasonable and necessary level of joint insight and cooperative implementation is required that involves all. While information for early, easy, and comfortable decision-making may be challenging to acquire, if we all rely on consistent fundamental principles (and not format/quantity), then most issues are not that difficult. ISS is truly a global multinational vehicle and needs to be treated as such by all.

8.5 Summary of Joint Cosmonaut-Astronaut EVA

The EVA WG (WG-7) coordinated spacewalk operations for astronaut and cosmonaut EVAs on *Mir* and the Shuttle for the NASA science program.

An agreement confirmed in the protocol of the meeting of September 28, 1994, established a program for conducting astronaut and cosmonaut EVAs during implementation of the *Mir*-Shuttle and *Mir*-NASA program. The *Mir* EVA program foresaw joint participation of astronauts and Russian cosmonauts in EVAs with the goal of carrying out the science program, inspecting the modules, and recovering operability of the systems as well as of the station assemblies. Shuttle EVAs for *Mir* were based on the situation on *Mir*.

Working with cosmonaut V. Tsibliev, J. Linenger was the first astronaut to conduct an EVA in an Orlan-DMA suit. The program, which included installation of an OPM, an external dosimeter array (EDA), an orbital debris collector (MSRE), and a panel with blanket samples (PIE), was completely fulfilled. Thermal luminescence dosimeters (TLDs) were installed on the space suits. The American-design joint safety tethers mounted on the Orlan-DMA suits were tested.

M. Foale and A. Solovyev conducted the second joint EVA on *Mir* in order to inspect the Spektr module. They also removed the Benton dosimeter. During the spacewalk, astronaut M. Foale demonstrated his expertise and capability of carrying out not just the planned program, but also operations which might be necessary during EVA. M. Foale's good knowledge of Russian also contributed to the success of his work.

The third astronaut, D. Wolf, and A. Solovyev successfully completed a joint spacewalk. Their goal was to work with the experimental spectroreflectometer SPSR. The EVA was successful, and unique data regarding the condition of the outer coating of several *Mir* surface areas were obtained.

During the STS-86 and *Mir*-24 mission, S. Parazynski and V. Titov, who were suited in EMUs, moved and fastened a large device designed to seal the Spektr solar array (Cb) drive from the Shuttle to the *Mir* docking compartment. The Russian restraint method utilizing two safety tethers was verified while working in the EMUs; mutually acceptable Yakor foot restraints for the ISS were tested.

Data on *Mir* EVA missions carried out jointly by the cosmonauts and astronauts are shown in Table 8.1.

Joint Shuttle/*Mir* EVAs

Table 8.1

№	Spacecraft (KK), Orbital Station (OC)	Crew	Date	Duration	EVA Operations	Space Suit (CK) CK-1, CK-2	Compartment
1	*Mir*-21	Onufrienko Usachev	06/06/96	3 hr. 34 min	Installation of PIE sample hardware; Installation of MSRE sample hardware	Orlan-DMA 25 Orlan-DMA 26	Special airlock (ШСО)
2	*Mir*-23	Tsibliev Linenger	04/29/97	4 hr. 58 min	Instillation and removal of U.S. science equipment. Installation of: optical properties monitor, external dosimeter array. Removal of: Kvant-II (ЦМ-Д) special airlock module (ШСО) debris collector (MSRE). Kvant II (ЦМ-Д) special airlock module (ШСО) panel with samples (PIE); Testing of joint safety tethers; Exposure of the TLD experiment dosimeters (2)	Orlan-M N4,5 Orlan-M N4,5	ШСО ШСО

Joint Shuttle/*Mir* EVAs

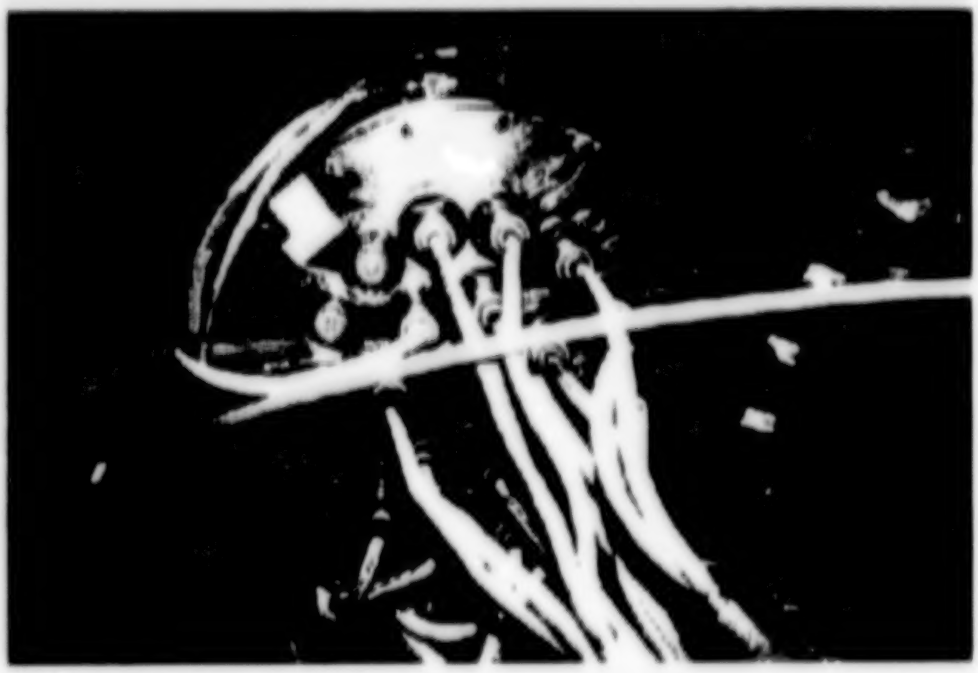
Table 8.1 Cont.

№	Spacecraft (KK), Orbital Station (OC)	Crew	Date	Duration	EVA Operations	Space Suit (CK) CK-1, CK-2	Compartment
3	*Mir*-24	A. Solovyev M. Foale	09/06/97	6 hr. 00 min	Inspection of the outer surface of the depressurized Spektr module (link rods 110, 111, 112, 113, 115 were inspected); Measurement of the gap around Б16 drive of the solar array (СБ-1V); Deployment of solar array (СБ-1V) and auxiliary solar array (ДСБ-1V); Removal of the American dosimeter Benton	Orlan-M N4,5	ШСО
4	*Mir*-24	A. Solovyev Vinogradov	01/09/98	3 hr. 06 min	Disassembly of the OPM and inspection of the special airlock (ШСО) hatch	Orlan-M N4,5	Instrument science compartment (ПНО)-ШСО
5	*Mir*-24	A. Solovyev David Wolf	01/14/98-01/15/98	3 hr. 52 min	Measurements using the SPSR device and inspection of the special airlock (ШСО)	Orlan-M N4,5	ПНО-ШСО

Joint Shuttle/*Mir* EVAs

Table 8.1 Cont..

№	Spacecraft (KK), Orbital Station (OC)	Crew	Date	Duration	EVA Operations	Space Suit (CK) CK-1, CK-2	Compartment
6	*Mir* STS-76	R. Clifford L. Godwin	3/27/96	6 hr, 03 min	Installment of MEEP on the docking compartment (CO)	EMU	Shuttle airlock
7	*Mir* STS-86	V. Titov S. Parazynski	9/3/97	5 hr, 01 min	Transfer and securing of the solar array (CБ) drive sealing unit cover on the docking compartment (CO); disassembly of MEEP equipment on the docking compartment (CO)	EMU	Shuttle airlock



Replacement Hatch for the Spektr Module

NASA 5 Astronaut Michael Foale on the treadmill aboard the *Mir*

Section 9 - Medical Support

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9.1 Introduction

The agreement of 5 October 1992 between the Russian Federation and NASA regarding collaboration in the area of crewed spaceflight, subsequent Russian Federation-U.S. intergovernmental understandings and agreements between the Russian Space Agency (RSA) and NASA, including the contract NAS 15-10110, specified the *Mir*-Shuttle and *Mir*-NASA program of joint crewed space missions.

The initial Phase 1 of the *Mir*-NASA project included the realization of the *Mir*-Shuttle program, and furthermore provided for:

1) Missions of Russian cosmonauts aboard the Space Shuttle;
2) Long-duration missions of American astronauts aboard the *Mir* space station;
3) Space Shuttle and *Mir* joint space missions with rendezvous and dockings, during which a NASA astronaut was rotated into the crew of the basic expeditions aboard the *Mir* station.

These efforts were realized within the scope of the Contract NAS15-10110 between the RSA and NASA.

Considering the considerable differences in the organization of the crew medical health and work fitness support systems in Russia and the U.S., the RSA and NASA medical hierarchies were faced with the complicated tasks of coordinating and integrating the organizational principles, methodology, requirements and medical means of both countries to support the health, work fitness, and professional life of the combined Russian-American crews, and of providing conditions for successful execution of the planned space programs. For this reason, WG-8 (Medical Support) was created in 1994 within the frameworks of Phase 1, which on the Russian side was directed by V.V. Bogomolov (Institute of Biomedical Problems [IBMP]-State Scientific Center) and V.V. Morgun (Gagarin Cosmonaut Training Center, or GCTC), and on the American side by Sam L. Pool and Roger Billica (Johnson Space Center, or JSC).

The main task of WG-8 was to develop the logistics to allow cooperation between the medical organizations that support the medical safety and health maintenance of the joint Russian-American crews in the training stages, during missions aboard the Russian and American transport vehicles (Soyuz TM, *Mir* Space Station, Space Shuttle STS), and after reentry.

9.2 Goals

The combined efforts were basically targeted toward:

- Coordination/approval and practical implementation of medical screening and health certification of the members of the joint crews;
- Biomedical training of the joint Russian-American crews in the mission programs at JSC and GCTC;

- Refinement and approval of joint requirements related to the medical procedures and equipment used to monitor the health of the crew before, during, and after a mission, to prevention of adverse body changes during a long-duration mission, optimizing the crews' diet, and to sanitary-hygienic, toxicologic and radiation monitoring of the crewed spacecraft habitat;
- Coordination, elaboration and refinement of crew on-orbit medical diagnostic procedures and equipment, and rendering medical aid when necessary;
- Coordination and optimization of the crew psychological support system;
- Training of medical personnel (flight surgeons) and their direct participation in the support of the space missions at MCC-Moscow and MCC-Houston (for flight surgeons: - NASA medical personnel when working at the GCTC and, at MCC-Moscow, and Russian medical personnel for flight operations when working at JSC in Houston);
- Development and operation of a material-technical base for gathering and processing the medical information that is obtained in the course of medical support of joint crewed missions, refining the communication facilities for the RSA and NASA medical support group specialists and preparing a basis for the development of telemedicine in the interests of mission on-line medical support.

At the subsequent stages of the work of WG-8, crew medical support on long-duration joint missions also included the implementation of the Space Medicine Program (SMP) -- using American medical equipment and procedures, in special investigations aboard the ***Mir*** station for the purpose of improving the crew health maintenance system and optimizing the elements of crew medical flight support aboard the ISS (monitoring the crew's habitat and health, means of rendering medical aid, microbiological and toxicological investigations, psychological monitoring and psychological support, radiation monitoring, and so on). From the standpoint of medical operations, Phase 1 of the program provided an opportunity to integrate the medical equipment and skills of both parties to continue preparing for crew health maintenance during and after long-duration spaceflight, and to establish lines of international communication and decision-making procedures, which are extremely important to the efforts within the scope of the ISS program.

9.3 Principles and Structure

The guiding principles of organizing the joint efforts for mission medical support under Phase 1 of the program included:

- Utmost regard and respectful consideration on the part of one partner for the knowledge and experience, and the developed regulations and procedures of the crew health maintenance system of the other partner, the search for acceptable compromises in keeping with the medical responsibility of each party for medical decisions made regarding their own crew members (RSA – in regard to the cosmonauts, NASA – in regard to the astronauts);
- Support of the standards, requirements, and national laws of biomedical ethics when conducting joint operations in different aspects of medical support;

- Striving toward candidness/openness between the parties' responsible medical representatives in regard to issues related to crew safety and health in all phases of executing the joint manned program.

Moreover, the medical support procedures and arrangements for the joint missions of the *Mir* basic expeditions were based primarily on Russian laws, and medical control of flight operations was managed by the Russian mission control in close cooperation with and including active participation of the NASA flight surgeon. Medical support of the Space Shuttle STS joint missions is based on NASA regulations. Mission Control-Houston provides the medical supervision of the flight procedures, which includes the active participation of the Russian flight surgeon, or an RSA medical official. Accordingly, the primary responsibility for the safety of the mission safety and maintenance of crew health during the *Mir* missions lay in the hands of the Russian partner, and during the Space Shuttle (STS) missions – the American partner.

To manage the practical operations related to the different collaborative aspects of crew medical health support during the Phase 1 program, work subgroups were created under WG-8 (Working Group 8), for crew biomedical training, crew health monitoring, on-orbit prophylaxis, psychological support, medical diagnostics and aid, nutrition, *Mir* atmospheric monitoring, radiation monitoring, on water supply, on implementing the SMP program, and for communications. Specialists of both parties within the scope of their subgroups coordinated their efforts toward practical implementation of the tasks to support the medical health and work fitness of the joint crews. They also conducted joint investigations, developed recommendations in complicated and off-nominal situations, and when medical problems arose. The leaders of WG-8 participated in the Phase 1 WG-8, and took active part in solving problems of medical safety when defining the scientific research program, in the on-orbit use and resupply of medical equipment and supplies, and drew up medical reports for the next stage of the Phase 1 program. Flight surgeons from both sides played an active role in this work.

9.4 Evaluating Crew Health and Medical Monitoring

The document WG-8/NASA/RSA/-E 8000, "The American-Russian Joint Space Program.-Phase 1. Medical Requirements," which was developed and approved by WG-8 on 29 March 1995, is the basic document that stipulates the joint requirements for medical support of joint missions. It includes the basic regulations that govern cooperation between the RSA and NASA medical structures in the training stages, during and after the missions. This document integrates the Russian and American requirements, and the provisions for medical support of spaceflight. It is founded both on the requirements and stipulations of the contract NAS 15 10110, and on prior agreements and understandings within the scope of the Continually Active Working Group on space biology, medicine and microgravitation. This document laid the groundwork for joint decisions regarding the medical flight readiness evaluation of American crew members for the *Mir* station missions. It is based on the provisions contained in the Requirements for Medical Operations aboard the Space Shuttle, JSC 13958, Paragraph E, and the Order of the USSR Ministry of Defense and Ministry of Public Health, No. 390/585, dated 21 October 1989, concerning the adoption of the Instructions for Medical Examination and Monitoring of cosmonaut candidates, cosmonauts, and cosmonaut instructors, and is based on the provisions and manuals that regulate the activities of the RSA and NASA medical support hierarchies.

The Chief Medical Board for Medical Support and Medical Problems performed the health certification of the astronauts to clear them for training at GCTC for *Mir* station missions, on the basis of the medical documentation submitted by JSC and the agreed quantity of examinations.

The JSC Medical Board conducted the health certification of the cosmonauts to clear them for a Space Shuttle mission, on the basis of the medical documentation submitted by the Russian party, and the agreed quantity of medical examinations.

Problems that arose were solved through coordination and discussion (personal meetings, teleconferences, facsimile communications) within the scope of WG-8, inviting the assistance of clinical experts from both countries when necessary. In complicated situations, the medical administrations of RSA and NASA (Joint Commission on Space Medicine) joined in solving medical problems, both before and during a mission.

For long-duration missions aboard *Mir*, the astronauts basically adopted the standard Russian system of medical health monitoring. The procedures and sequence of on-orbit medical examinations of the astronauts were coordinated and approved by the American flight surgeon. The quantity and extent of the tests/investigations are given in Appendix 1 and 2.

Moreover, the American flight surgeons conducted regular confidential medical interviews with the basic expedition astronaut, and also conducted additional approved medical health tests on the astronaut, and evaluated his/her physical fitness within the scope of the American SMP (Appendix 3, SMP).

The NASA flight surgeon at MCC-Moscow was fully informed of the results of standard crew medical monitoring, and likewise provided information to the medical directors at MCC-Moscow concerning the outcome of medical monitoring under the American program. Good working cooperation and mutual understanding were established as a result of the joint efforts of the NASA flight surgeon and the Medical Support Group (ГМО) at MCC-Moscow.

Under Phase 1 of the program, the results of the crew member in-flight medical exam required a special discussion by the medical specialists of both parties with adherence to bioethical standards. Furthermore, it should be noted that the results of crew medical health and physical fitness monitoring adequately reflected the crew members' health dynamics, and permitted necessary adjustments to the medical support program.

The appropriate adjustments were made for female astronauts and certain other astronauts in the medical monitoring program by consent of the American party.

Approval of the Phase 1 medical monitoring flight program by the medical and biomedical subgroup specialists made it possible to:

- Introduce new data collection equipment aboard the *Mir* station, and
- Refine the integrated response procedure of Russian and American ground services to mission medical problems in real time.

Russian cosmonauts among the crew of the Space Shuttle STS, before, during and after a mission, utilized the health monitoring system in effect at JSC with the participation of the Russian flight surgeon. In the process, the medical monitoring and medical examination program at the preflight training stage was modified upon consent of the Russian party to take into account the individual features of age and sex.

On the basis of the knowledge and experience gained during Phase 1, the "NASA and RSA Tentative Approach to Questions of ISS Medical Policies" was developed, and was approved on 21 November 1996, and the Requirements for Medical Examinations and Health Standards (AMERD) were refined later on a multilateral level for the ISS crews. Examination norms that are acceptable to all ISS partners were adopted. The positive outcomes of these documents include the following:

- A clear understanding of the problems of medical ethics in both countries, as well as the population differences;
- Better understanding by American medical operations specialists of the physical and psychological factors characteristic of long-duration spaceflight, including the launch and reentry aboard the Soyuz TM spacecraft, which must be considered in the primary medical examination;
- Establishment of lines of communication among medical specialists of U.S. organizations on the one hand, and organizations of the Russian Ministry of Defense and Ministry of Public Health, on the other, which are currently in use during conversations concerning the ISS joint efforts.

9.5 General Crew Training Overview

All in all, 7 NASA astronauts were trained at the Yuri A. Gagarin Cosmonaut Training Center (GCTC) for long-duration space missions aboard the orbital station *Mir* as flight engineers-2, and 4 astronauts were trained for EVA, under the *Mir*-NASA Program.

To implement the joint Russian-American science program two training sessions were held at the Johnson Space Center and as many at the GCTC involving the primary and backup crews of the *Mir*-21, *Mir*-22, *Mir*-23, *Mir*-24, and *Mir*-25 missions.

Four Russian cosmonauts (Kondakova, Titov, Sharipov and Ryumin) had their training at JSC as members of the American crews in preparation for flights aboard Space Shuttle and performed these flights under the *Mir* NASA program.

Nine Shuttle crews (STS-71, -74, -76, -79, -81, -84, -86, -89, -91) took a week-long training in Russia to study the *Mir* systems for joint activities with the Russian crews. The Russian *Mir*-20-25 primary and backup crews took their week-long training at JSC to study the Shuttle systems and to get orientation in joint activities with the STS crews (altogether, six times). Training of the *Mir*-18 and -19 crews took place in the framework of the joint *Mir*-Shuttle missions.

The biomedical training of NASA astronauts in preparation for space missions aboard the *Mir* research complex was carried out at the GCTC in two stages:

- training specifically programmed for a group of astronauts
- crew training.

9.6 Astronaut Training

Astronaut training included the following areas:

- fundamentals of aerospace medicine;
- medical health monitoring and examination;
- physical training;
- medical tests, studies and exercises;
- preparation for joint activities.

The biomedical training of astronauts and cosmonauts as a group and during the following stages was done with a due account of their background knowledge.

The purpose of biomedical training of astronauts was to ensure a good physical condition, good functional psychophysiological capabilities of the body, and a high level of performance through the following:

- preserve and improve health, maintain high level of fitness and keep the body in good condition,
- organize and conduct medical investigations and training to maintain a good level of stabilization in exposure to spaceflight factors,
- know health monitoring procedures,
- use onboard countermeasures,
- operate life support systems of a specific crewed spacecraft,
- use onboard sanitary, epidemiological, and radiation protection measures,
- acquire skills in disease diagnostics, and using onboard medical supplies and countermeasures.

Biomedical group training program included the following basic issues:

- organization of medical support during human spaceflights,
- effect of spaceflight factors on the human body in lengthy flights,
- psychological aspects of a long-duration spaceflight, and psychological support methods,
- medical monitoring systems of a space vehicle and a space station,
- physical training.

By solving these problems successfully the main objective was attained, that of ensuring a required level of astronauts' professional training that was necessary for continuing crew training.

9.7 Biomedical Crew Training

The purpose of biomedical crew training was to provide a set of medical supplies and countermeasures to ensure the crew's good health status, high performance, readiness to accomplish the biomedical objectives and the mission as a whole.

The basic biomedical goals of crew training are as follows:

- establish dynamic health monitoring and preventive medical treatment measures to preserve and maintain good health and to promote physiologic capability and performance during spaceflight training and realization,
- increase psychophysiological tolerance to exposure to spaceflight factors during training using special stands and simulators,
- adjustment of individual psychological qualities and specific features of crew members' interaction,
- train crew to perform specific biomedical research and experiment procedures,
- in-flight baseline data collection procedures for medical monitoring purposes,
- arrange and perform a set of hygiene and sanitary measures, and a quarantine program.

Data for the extent of biomedical astronaut training is shown in Table 9.1.

Crew training included:

- medical health monitoring,
- increasing tolerance to spaceflight factors,
- study of medical support available on the transfer vehicle and the *Mir*,
- practical lessons and training sessions using simulators and other facilities of the transfer vehicle and the space station,
- getting grounding in the technical aspects of the medical monitoring aids of the crew transfer vehicle and the orbital station,
- *Mir*-NASA research program training,
- physical training.

Medical health monitoring was carried out by the American and Russian specialists in compliance with the "Joint U.S.-Russian Phase 1 Program. Medical Requirements." The quantity and aspects of medical monitoring are shown in Table 9.2.

Training aimed to increase tolerance to spaceflight factors did not involve all areas. By agreement with the American specialists training was performed in pressure chambers and centrifuge with g-loads related to the ascent and descent timelines. In view of the specific features of Soyuz missions, lectures were read on spaceflight factors. The GCTC specialists also carried out medical operations to support the activities of cosmonauts during training in hydrolab and during flights in the IL-76MDK laboratory aircraft for microgravity simulation. The quantity of training in this area is given in Table 9.3.

Training in the medical support of the transfer vehicle and station was conducted in conformity with the data initiated by the RSC-Efor the flight-specific training of the *Mir*-NASA crews. The extent of training in this area is presented in Table 9.4.

Practical experience was gained in operating medical monitoring and preventive measures in the context of learning the MK-1 procedures (bioelectric cardiac activity), MK-4 (lower body negative pressure), and MK-5 (cardiovascular system performance under physical stress), MK-8, MK-108, MK-120, MK-12.

The astronauts have studied the purpose, composition, and location of the medical monitoring facilities and the equipment used to ward off the adverse effects of weightlessness on board the *Mir*. They have acquired stable skills to operate this equipment and also learned to provide maintenance and to control off-nominal situations.

The astronauts have received a fairly thorough grounding in the uses of medical equipment to perform scientific biomedical experiments and they developed and reinforced the skills required to operate them without assistance.

The cosmonauts' physical training consisted of general physical and special physical exercises, and also they have learned to use onboard physical training aids. The results are presented in Table 9.6.

9.8 Role of Russian Flight Surgeons

Russian flight surgeons provided medical support for training at NASA. Their activities included:

1. Training in the medical operations program for American spaceflights
2. Medical care of the crew members during their training sessions:
    - providing medical assistance;
    - medical monitoring of their health;

- participating in medical lessons on medical equipment and on how to render medical assistance on board;
- monitoring their physical training.

3. Provision of medical assistance to representatives of Russian organizations
4. Performing a liaison role between the management of medical subdivisions at NASA and RSA during the resolution of urgent issues in medical care for Phase 1 and the beginning of Phase 2.

9.9 Conclusions and Recommendations for the Overall Medical Support Program

Joint training with the crew members enabled the astronauts to perform tasks successfully in the training program as part of the crew and to acquire skills at the required level in performing tasks for the biomedical section of the spaceflight program.

In the opinion of the Russian crew members and the American astronauts who worked on the *Mir*-NASA program during the stage of training as part of Russian-American crews, more attention should have been paid to issues of psychological compatibility among the crew members. For this purpose, more prolonged training should be conducted within each crew, with whom one would have to work later on board the *Mir* Space Station. This could also be improved by holding joint training sessions on how to live under extreme conditions.

The results of examination during final simulation training sessions showed that the main objective was achieved, i.e. the crew's level of professional training proved to be sufficient for them to be certified for spaceflight and to carry out the science program on board the *Mir* Space Station.

It would be advisable to use the experience acquired in training crews on the *Mir*-NASA program when the ISS crews are trained.

9.10 Accomplishments and Lessons Learned

9.10.1 Preventing On-Orbit Adverse Changes in the Body

The Russian system of prophylaxis was relied on to protect the crews of long-duration expeditions from the adverse effects of flight conditions in Phase 1. A regular program of prophylaxis was prescribed for the Russian members of the joint crews that basically involved physical exercises with the onboard exercise training equipment (the UKTF physical exercise training complex, and the VB-3) and expanders according to a special 4-day routine, wearing the flight loading suits (Penguin), cyclic administration of pharmaceuticals (cardiotropic, nootropic, eubiotics), a cycle of low body negative pressure exercises, and ingestion of nutritional additives in the final stage of the long-duration mission, ingestion of water-salt additives on the eve and the day of landing, the use of means to protect against g-forces in the descent phase and early on in the postflight period. The use of constrictive femoral cuffs for the Russian crew members is optional in the system of flight prophylaxis.

The flight prophylaxis program for the NASA astronaut crew members of the basic expeditions aboard the *Mir* station, largely consisted of physical exercises on the flight exercise equipment according to regimens that approximated those recommended by the Russian party, and the optional use of the flight loading suit. The American party refused the low body negative pressure exercises in the final phase of the mission, and prophylactic courses of pharmaceuticals. Since the astronauts were returned to Earth aboard the Space Shuttle, following the advice of the NASA physicians, they adhered to the American system of salt-water loading the day of landing, and the American g-force protections (the American flight suit), though the Russian "Centaur" anti-gravity suit was available if necessary in the early postflight period.

All crew members were advised to wear special earphones to protect their hearing.

For the most part, with little exception, the astronaut members of the basic expeditions aboard the *Mir* station attempted to heed the advice of the physical prophylaxis specialists that was conveyed to them directly, or through the American flight surgeon. While the NASA-6 and NASA-7 programs were in progress, the American exercise physiologists and NASA flight surgeons recommended several regimens and systems of physical exercises apart from the Russian ones, which the American party considers as promising for the ISS. The results of these refinements must be reviewed by specialists from both sides.

The general conclusion amounts to the fact that the state of health of the crew of long-duration missions, and not just while on orbit, but also after their completion, depends on how fully the program of preventive measures is followed, particularly the physical preventive measures. This applies both to the Russian cosmonauts, and to the American astronauts of the basic expeditions. The efficacy of the flight prophylaxis must be thoroughly reviewed once the Russian specialists have acquainted themselves with the results of the postflight clinical and physiological tests performed on the astronauts after a long-duration mission.

9.10.2 Rendering Medical Assistance

Throughout Phase 1, the Russian and American specialists carried out a whole array of efforts aimed at formulating and refining the onboard diagnostic equipment and rendering first aid, by incorporating the American medical kits and medical first aid equipment (defibrillator, crew member fixation/immobilization system, medical therapy sets).

The quantitative and qualitative inventory of the American kit (MSMK) and the Russian medical kits was reviewed jointly, and approved. The decision was made to use both the American and Russian medical supplies, which was the practice used to treat individual crew members. The Russian version of the American flight data files for the diagnostic equipment and medical supplies (Medical Checklist) was reviewed and modified/corrected; defibrillator operating instructions (Defibrillator cue cards) were developed.

The expansion of the therapeutic capabilities of the onboard medical equipment and supplies greatly enhances the reliability of the medical aid flight system as a whole. The prospects for refining the diagnostic aids and rendering emergency medical treatment to ISS crew members have been determined.

9.10.3 *Mir* Habitat Monitoring

In the course of implementing Phase 1 of the *Mir*-NASA project, particular attention was paid to evaluating the condition of the habitat of the basic crews aboard the *Mir* station, as determined in part by the length of service of the station, and periodic deviations and failures on the part of the life support systems. Emergency situations occurred as well (ignition of the solid fuel oxygen generator cartridges, depressurization of the Spektr module due to a collision with a Progress cargo vehicle, failures in the complex control system with a power shortage aboard the station). Because of their possible medical consequences, these situations demanded special attention and a quick response of the technical and medical ground services. In 1997, the toxicologic hazard related to ethylene glycol that entered the station atmosphere due to a leak in the thermal control system aroused special concern.

In these situations, the Russian and American specialists maintained regular contact (teleconferences and meetings) to keep one another informed, and to develop consensual decisions regarding medical arrangements (additional medical monitoring and crew health observation, station atmospheric and water supply testing and monitoring, prophylactic and preventive measures for the crew, additional deliveries of medical supplies to the station).

During this time standing commissions of specialists at RSC-E and the IBMP worked to develop and implement recommendations in order to gain control of the off-nominal situations as quickly as possible. These commissions were staffed with a profile of the most competent technical, toxicological, and medical specialists.

Besides the repair equipment, additional Russian and American means for toxicology monitoring, air- and water-quality testing equipment, and therapeutic and protective equipment were also delivered to the *Mir* aboard the Progress and Space Shuttle vehicles.

The results of medical health monitoring of the crew members conducted at these times and on completion of the missions, usually failed to disclose any adverse changes in body health, though the periods of forced limited use of flight prophylactic equipment, and stressful work/rest regimens in such conditions undoubtedly diminished the efficacy of the medical support system.

The basic outcome of these efforts was the unique combined experience gained in addressing medical and medical-technical problems in various off-nominal and emergency situations during a long-duration mission. Moreover, a number of American crewed spacecraft habitat monitoring aids were approbated in long-duration mission conditions, and their positive and negative aspects were identified, which is extremely important for ISS operations.

9.10.4 Nutrition System

The nutrition subgroup of WG-8, including Russian specialists (from the IBMP-State Scientific Center, the Scientific Research Institute GCTC) and specialists from JSC, completed extensive efforts to discuss and adopt the "Food Standards for *Mir*-NASA Program Crews," and to develop and adopt the "Phase 1 Nutrition Plan." The requirements and procedures for microbiological and toxicological quality control of crew member food rations were approved. The acquisition and delivery of joint Russian-American rations to the *Mir* station aboard the Progress and Shuttle vehicles were defined.

Individualized menus were developed for each expedition based on personal preferences. The adoption of a joint Russian-American ration for the crews of Phase 1 greatly expanded the variety of foods and diversified the rations. Using these rations demonstrated that the bodily requirements of the crew members for basic food components and energy were being met. By and large, the crew members of *Mir*-21–*Mir*-25/NASA-1–NASA-7 rated the joint rations favorably, while offering certain suggestions and recommendations, which were taken into consideration in developing the menu for the first ISS crews. The experience and knowledge gained here during Phase 1 made it possible to develop "The Nutritional Plan for ISS Assembly," and the menu list for the first basic crew, which were approved.

9.10.5 Flight Medical Equipment

The opportunity to gain experience in joint operations aboard the *Mir* station required the development of a new American medical kit, which was better and more complete than any of its U.S. aerospace predecessors.

The systems specialists and their partners supported the work of 7 meetings on flight equipment integration that took place from 1994 through 1997, with each new mission expanding the volume of American equipment aboard *Mir*.

A unified training program for ISS missions was developed in order that the Russian cosmonauts and American astronauts would receive identical training for work on the ISS medical equipment.

- The contribution of the astronauts, cosmonauts, and Russian flight surgeons to the training and use of medical kits is being applied to improve the American medical supplies and procedures for the ISS.
- Within the scope of the Phase 1 program, the American and Russian specialists trained all *Mir* station crew members in the use of flight medical equipment and procedures, thereby ensuring reliable mutual familiarity with the medical supplies in accordance with the training objectives, so that the resources of both sides might to used to the fullest, including all pharmaceuticals, diagnostic, and therapeutic equipment.
- An important step forward in the development of American flight operations support facilities was the decision to procure and deliver a defibrillator and a crew member medical immobilization/fixation system to the *Mir* station for the NASA-5 mission. The experience acquired in the process of this effort will be utilized in providing the ISS with medical material, and in the possible use of such material by the ISS crews.
- Experience from Phase 1 made it possible for the U.S. ground medical support services to acquire the skills for rapid innovation of medical equipment and supplies. The mutual confidence and experience gained in the implementation of the Phase 1 program afforded the development of procedures to effectively rate the safety of onboard medical equipment. For instance, when *Mir*'s Spektr module was damaged during NASA-5, the medical operations specialists, in conjunction with their Russian partners, expeditiously replaced the American medical system damaged in the Spektr module. The new equipment was produced, outfitted and certified by the American medical operations specialists within 24 hours. The new medical equipment was processed and shipped to Russia for delivery to the *Mir* station aboard a Progress cargo vehicle. Representatives of the IBMP and RSC-E ensured that these American medical kits were delivered quickly and smoothly to the Russian launch site.
- The onboard availability of both the Russian and American medical kits dictated the need for a spare medical kit, which should be used as a "central supply."

- This dialog greatly broadened the knowledge and experience of the NASA medical specialists in regard to the anticipated medical risk of long-duration spaceflight. The Russian medical operations service has presented an extensive list of the medical problems, which occurred during the Salyut and *Mir* programs, helping the American party to finalize the development of the medical kits and to train the ground support services for Phase 2 operations.

9.10.6 Behavior and Work Fitness

Practical psychology and psychiatry evolved as the Russian and American specialists together supported the condition of the crew aboard the *Mir* orbital station and Space Shuttles. A broad range of behavioral and work-fitness problems was studied at NASA in support of the long-duration missions in which U.S. astronauts participated, namely:

- A permanent behavior modification and work-fitness program was established within the hierarchies of the NASA medical service. This service was charged with the task of developing and implementing all means necessary to support the psychic health, work-fitness and well-being of an American astronaut aboard *Mir*, and to provide for the needs of the ISS crew members.

- The Russian and American psychological support services reached mutual understandings in the methods and mission culture. An American psychological support program that continued the existing Russian program was established. It included:

  - Two-way audio and video links between JSC (NASA), GCTC, and the *Mir* station;
  - Uplinks of local and national news from the U.S. through Mission Control;
  - A personal collection of books, musical recordings, CDs and video tapes for rest and relaxation;
  - An e-mail system between the *Mir* station and the astronaut's home and workplace;
  - Regular delivery of personal packages from families, friends and the psychology service aboard a Progress cargo vehicle;
  - Informational, emotional, and substantial support of families and close friends and associates of astronauts aboard the *Mir* station;
  - The addition of a short-wave ham radio as means of support for families and crew members;
  - A feedback procedure based on computerized programs introduced by the American party as a means of observing and supporting the state of the crew, and also of monitoring the efficacy of the psychological support and better understanding the influence of these measures on the psychological state.

- The parties shared information and offered mutual support to facilitate social adaptation of the crew and reciprocal understanding of all crew members.
- The American party developed a crew psychological training program to familiarize them with the flight conditions, adaptation techniques and psychology lessons of past Russian and U.S. missions, and with similar activities in polar, underwater and other remote, self-contained situations. The American training program also included a course on Russian culture.
- The American party developed the computerized Spaceflight Cognitive Assessment Tools (SCAT), which allowed the astronaut to evaluate his own cognitive functions. This instrument was deemed necessary in view of the peculiarities of the habitat in long-duration spaceflight, where exposure to toxic substances, adverse atmospheric changes in an enclosed volume, and head trauma are possible.
- The behavior modification and work fitness experts also had direct access to the experience of our Russian colleagues, and experience of the mission as a whole, in regard to:

  – Preflight training and establishing a routine;
  – On-orbit crew member medical support and behavior modification;
  – Interaction and operation of ground services;
  – Direct daily interaction with the Russian medical and psychological support group;
  – Postflight re-adaptation and establishing an activity routine. (One of these experts was also a NASA Flight Surgeon of the Phase 1 Program)

The Russian psychological support system aboard the *Mir* space station, which was used in Phase 1 of the *Mir*-NASA project, is depicted in the diagram in Appendix 4. The psychological support logistics for NASA 1–7 are presented in the Table in Appendix 5.

9.10.7 Postflight Readaptation

The Phase 1 program afforded the American party the opportunity to utilize the extensive Russian experience in developing a postflight readaptation program. On the whole, this program rather effectively facilitated the returned crew members' continuation of an active lifestyle in normal Earth gravity. Though all American astronauts who flew aboard the *Mir* were returned to Earth aboard Shuttles, Russian flight surgeons were present at the landing site after each Shuttle/*Mir* mission. Because of the cooperation between Russian and American exercise physiologists throughout the execution of Phase 1, the program of rehabilitation measures for the ISS crews include the appropriate modifications for the reentry phase. Examples of the most important lessons of our cooperation include:

- The fact that the program of mandatory physical exercises before and during a mission is critical to the maintenance of physical shape in space, and at the same time affects the rate and entirety of complete readaptation to ground conditions after a mission;
- The use of loads/weights in an aquatic medium as a conservative, safe method of restoring the muscles, bones and ligaments for the return to intense activity on Earth;
- The importance of the crew members spending long vacations with their families prior to another mission appointment.

9.11 Summary of the Medical Support Group's Accomplishments

On the whole, one of the most important positive results of the Phase 1 program, which by the way is rather difficult to measure, is the experience in cooperation that was gained by the RSA and NASA ground medical services during the missions. Both parties now are more effectively maintaining bilateral and multilateral (with other international partners) dialogs, which is crucial to solving on-orbit off-nominal situations. With the help of the Russian colleagues and through the use of Russian experience, the American medical operations specialists have learned much during the implementation of Phase 1 in regard to the preparation for and real-time response to complicated situations that are more likely to occur in long-duration spaceflight.

- Another important outcome of the medical support of joint long-duration missions is the preservation of the health and functional reserves of members of the basic expeditions, which ensured both the execution of the mission, and the relatively favorable course of the readaptation processes after the completion of the missions.

- The tasks charged to Phase 1 WG-8 at this time are finished; a joint discussion and review of the clinical and physiological aspects of the completed operations still remains for the work to be finalized. It is best if the experiences of the combined efforts for the crew medical health support of Phase 1 are utilized to the utmost in order to solve the medical problems of ISS deployment and operation.

Dates and Quantity of NASA Astronaut Training

Table 9.1

Mission, Astronaut (backup)	*Mir* Operation Start/Finish Dates	Training With Russian Crew (backup)	Astronaut Training Dates (generic/crew)	Total Biomedical Training Hours
NASA-2 Shannon Lucid (John Blaha)	⇑STS-76 03/24/96 ⇓STS-79 09/26/96 (188 days)	*Mir*-21 Onufrienko, Usachev (Tsibliev, Lazutkin)	01/03/95 - 06/24/95 06/26/95 - 02/26/96	273
NASA-3 John Blaha (Jerry Linenger)	⇑STS-79 09/16/96 ⇓STS-81 01/22/97 (129 days)	*Mir*-22 Korzun, Kalery (Manakov, Vinogradov)	02/23/96 - 07/01/96 05/29/95 - 07/19/96 (4/14 months)	337
NASA-4 Jerry Linenger (Michael Foale)	⇑STS-81 01/12/97 ⇓STS-84 05/24/97 (132 days)	*Mir*-23 Tsibliev, Lazutkin (Musabaev, Budarin)	09/23/96 - 06/12/96 11/29/95 - 12/20/96 (2.5/13 months)	388
NASA-5 Michael Foale (James Voss)	⇑STS-84 05/15/97 ⇓STS-86 10/07/97 (145 days)	*Mir*-24 Solovyev, Vinogradov (Padalka, Avdeev)	01/13/97 - 04/09/97 03/04/96 - 04/30/97 (3/14 months)	277
NASA-6 David Wolf (Wendy Lawrence)	⇑STS-86 09/26/97 ⇓STS-89 01/31/98 (128 days)		09/02/96 - 08/27/97 09/02/96 - 08/12/97 (12/11.5 months)	410
NASA-7 Andrew Thomas (James Voss)	⇑STS-89 01/22/98 ⇓STS-91 06/11/98 (139 days)	*Mir*-25 Musabaev, Budarin (Afanasiev, Treshchev)	01/16/97 - 12/05/97 09/08/97 - 12/05/97 (10.5/3 months)	402

Listing and Quantity of NASA Astronaut Health Monitoring

Table 9.2

Mission (Prime, Backup)	Chief Medical Board	Physiologic Clinical Examination	Phased Medical Examination	Medical Diagnostics & Therapeutics	Training Sessions
NASA-2 (Lucid, Blaha)	6	32	3	2	8
NASA-3 (Blaha, Linenger)	4	16	0	2	-
NASA-4 (Linenger, Foale)	4	32	2	2	-
NASA-5 (Foale, Voss)	4	32	2	2	-
NASA-6 (Wolf, Lawrence)	4	32	3	6	-
NASA-7 (Thomas, Voss)	6	32	2	6	9

Areas and Quantity of Astronaut Training in Spaceflight Factors (hours)

Table 9.3

Mission, Astronaut (backup)	Theory of Spaceflight Factors	Diving Physiology and Medicine (Lecture and Credit)	Centrifuge g-loads Training	High-Altitude Training and EVA Medical Monitoring (pressure chamber)
NASA-2 Shannon Lucid (John Blaha)	2	-	-	11
NASA-3 John Blaha (Jerry Linenger)	2			11
NASA-4 Jerry Linenger (Michael Foale)	2	3	1	14
NASA-5 Michael Foale (James Voss)	2	3	1	23
NASA-6 David Wolf (Wendy Lawrence)	2	3	1	17
NASA-7 Andrew Thomas (James Voss)	2	3	-	17

Biomedical Mission Program Training (hours)

Table 9.4

Mission, Astronaut	Psychological Training	Medical Support Aids	Mission Science Program
NASA-2 Shannon Lucid	2	6	39
NASA-3 John Blaha	8	21	101
NASA-4 Jerry Linenger	8	13	116
NASA-5 Michael Foale	2	4	65
NASA-6 David Wolf	8	23	160
NASA-7 Andrew Thomas	6	21	160

NASA Astronaut Technical Training (hours)

Table 9.5

Mission, Astronaut	Nominal Medical Monitoring and Countermeasures Equipment on Board	Science Hardware (NASA)
NASA-2 Shannon Lucid	4	6
NASA-3 John Blaha	4	18
NASA-4 Jerry Linenger	4	7
NASA-5 Michael Foale	4	3
NASA-6 David Wolf	4	13
NASA-7 Andrew Thomas	4	4

Astronaut Physical Training (hours)

Table 9.6

Mission, Astronaut	General Physical Training	Special Physical Training	Onboard Countermeasures
NASA-2 Shannon Lucid	100	40	12
NASA-3 John Blaha	102	40	8
NASA-4 Jerry Linenger	110	60	10
NASA-5 Michael Foale	80	40	12
NASA-6 David Wolf	90	30	14
NASA-7 Andrew Thomas	90	30	10

GENERAL INFORMATION

on Medical Support of *Mir*-NASA Phase 1 Joint Crew Flight on *Mir* (NASA 1-7)

Program	NASA-1	NASA-2		NASA-3	NASA-4	
Astronaut	N. Thagard	S. Lucid		J. Blaha	J. Linenger	
Mission	*Mir*-18 V. Dezhurov G. Strekalov	*Mir*-21 Yu. Onufrienko Yu. Usachev	*Mir*-22 V. Korzun A. Kaleri	*Mir*-22 V. Korzun A. Kaleri	*Mir*-22 V. Korzun A. Kaleri	*Mir*-23 V. Tsibliyev A. Lazutkin
NASA Surgeon	M. Barratt D. Ward	G. Johnson		P. McGinnis	T. Marshburn	
Launch	03/14/95 Soyuz-TM-21	03/22/96 *Atlantis*		09/16/96 *Atlantis*	01/12/97 *Atlantis*	
Mir Docking	03/16/95	03/24/96		09/19/96	01/15/97	
Mir Undocking	07/04/95	09/24/96		01/19/97	05/21/97	
Return to Ground	07/07/95 *Atlantis*	09/26/96 *Atlantis*		01/22/97 *Atlantis*	05/24/97 *Atlantis*	
Total Flight Duration	115 days 8 hrs 43 min	188 days 4 hrs		128 days 5 hrs 28 min	132 days 4 hrs	
Aboard *Mir*	109 days 4 hrs 25 min	183 days 23 hrs		122 days 23 hrs 01 min	126 days 21 hrs 09 min	
Medical Monitoring						
MK-1 (ECG at rest)	2	4		3	3	
MK-4 (LBNP Test)	1	2		1	-	
LBNP Training	2	-		-	-	
MK-5 (Graded Physical Load on VB-3 Cycle Ergometer)	1	3		2	2	
MK-6 (Body Mass)	14	11		9	7	
MK-7 (Calf Volume)	3	9		8	6	
EVA Medical Monitoring	-	-		-	1	

Appendix 1 Cont.

Program	NASA-5		NASA-6	NASA-7	
Astronaut	M. Foale		D. Wolf	A. Thomas	
Mission	*Mir*-23 V. Tsibliyev A. Lazutkin	*Mir*-24 A. Solovyev P. Vinogradov	*Mir*-24 A. Solovyev P. Vinogradov	*Mir*-24 A. Solovyev P. Vinogradov	*Mir*-25 T. Musabuyev N. Budarin
NASA Surgeon	T. Taddeo		C. Flynn	P. McGinnis	
Launch	05/15/97 *Atlantis*		09/26/97 *Atlantis*	01/23/98 *Endeavour*	
Mir Docking	05/17/97		09/28/97	01/24/98	
Mir Undocking	10/04/97		01/29/98	06/8/98	
Return to Ground	10/07/97 *Atlantis*		02/01/98 *Endeavour*	06/12/98 *Discovery*	
Total Flight Duration	144 days 13 hrs 47 min		127 days 20 hrs 01 min	140 days 15 hrs 12 min	
Aboard *Mir*	139 days 14 hrs 55 min		123 days 20 hrs 50 min	134 days 19 hrs 47 min	
Medical Monitoring					
MK-1 (ECG at rest)	3		3	3	
MK-4 (LBNP Test)	-		1	1	
LBNP Training	-		-	-	
MK-5 (Graded Physical Load on VB-3 Cycle Ergometer)	1		2	2	
MK-6 (Body Mass)	6		8	9	
MK-7 (Calf Volume)	4		7	8	
EVA Medical Monitoring	1		1	-	

Russian - U.S. Joint Contributions to the Phase 1 Medical Program

CARDIOPULMONARY			
Defibrillator / CMRS		Defibrillator / CMRS	*Mir* 23 / NASA 5
EKG at rest	MK-1		*Mir* 18
EKG with ergometer	MK-5		*Mir* 18
Hematocrit	MK-120	MO-9; Portable Clinical Blood Analyzer / Venipuncture	*Mir* 18
Holter Monitoring	MK-44-4		*Mir* 18
LBNP	MK-4	MSD008; Automatic Blood Pressure Cuff	*Mir* 18
ENVIRONMENTAL			
Acoustic Noise Measurements		MSD084; *Mir* Acoustic Dosimeter	*Mir* 25 / NASA 7
Air Quality assessment	MK-40-5	MO-14 / MSD007 Solid Sorbent and Grab Air Samplers; Formaldehyde Monitors	*Mir* 18
Air / Surface Microbiology	MK-35	MSD022; Microbial Air Sampler, Surface Sampling Kits	*Mir* 18
Crew Microbiology	MK-10	MSD021	*Mir* 18
In-flight Radiation Monitoring	Area Dosimeters	MO-12 / MSD004 Tissue-Equivalent Proportional Counter (TEPC), Area Dosimeters, Personal Dosimeters	*Mir* 18
Special Environmental Assessment	Drager Tubes	Combustion Products Analyzer, Real Time and Archival Sampling Kits for Ethylene Glycol and Carbon Monoxide	STS-84, *Mir* 23 / NASA 5
Water Quality: Chemical assessment Microbiological assessment		MSD022, MAD053 Water Experiment Kits, Refrigerated samples, Microbial Capture Devices	*Mir* 18
MEDICAL			
Blood Chemical Analysis	MK-12	MO-9; Portable Clinical Blood Analyzer	*Mir* 18
Crew Status and Support Tracker (CSST)	Review of questions contained in CSST	CSST software	NASA 3
Cognitive Assessment		MO-6 / MSD085 SCAT software	*Mir* 25 / NASA 7
Photodocumentation of Skin Injuries		MSD076	*Mir* 23 / NASA 4
Urinalysis	MK-27, Mk-28	MO-9 (Human Life Sciences project contributed Dried Urine Chemistry capability)	*Mir* 18
PHYSICAL FITNESS			
Arm Ergometry	MK-8		NASA 4
Body Mass Measurement	MK-6		*Mir* 18
Physical Training Assessment	MK-108-2	MSD077 Heartwatch, Automatic Blood Pressure Cuff, Cycle Ergometer	*Mir* 18

SMP *Mir*-NASA Phase 1 Research Content

CODE	EXPERIMENT DESCRIPTION	OPERATIONAL CONTENT
MO-1	Private Medical Conferences	Astronaut communication with NASA surgeon on closed loop
MO-9	Physical	a) self-evaluation of physical condition (Russian Form 20) b) blood chemical analysis using PSBA
MO-10	Urine Sample Analysis	Biochemical blood (sic!) analysis using indicator strips
MO-11	Radiation Data Download from TEPC	Once a month - TEPC data download to MIPS hard drive - data reduction and creation of a small file for TLM-downlink - data transfer to optical disks Once a week - TEPC display data report during comm pass
MO-12	Radiation Monitoring	- a personal dosimeter is worn by an astronaut from launch to landing - 18 passive dosimeters are installed on panels inside the station's modules (Passive dosimeters are replaced during NASA mission handover)
MO-14	Environmental Anomalies Affecting Health	Air sampling for formaldehyde levels using - personal (located on astronaut clothing - 12 hrs); and - local (station panels - 24 hrs) samples
MO-8	Record of MSMK Pharmaceutical Intake	Bar code logger is used to read the bar code of any pharmaceutical from the kit
MO-2	Download of General MSMK Utilization Data from Bar Code Reader	- Download of Bar Code Logger data on the use of the medical kits into MIPS - transfer to optical disks - TLM data downlink
MO-6 (CSST)	CSST Name changed as of NASA-5: Assessment of Crew Psychological Condition and Effectiveness of Psychological Support Measures	Completion of computerized questionnaire
MSD053 (WATER)	Archive Water Sample Analysis	Condensate Sampling (into Russian samplers) *Mir* Potable Water Sampling
MSD021 (Crew)	Crew Microbial Assessment	Crew sample collection. Swab samples are taken from different parts of the body (skin and mucous membranes). Samples are frozen in microbial medium.

Appendix 3 Cont.

CODE	EXPERIMENT DESCRIPTION	OPERATIONAL CONTENT
MSD021 (MICRO)	*Mir* Microbial Assessment	- Water, air, and surface sample collection for in-flight microbial analysis - colony count at 2 and 5 days (occasional photography and video filming) - count reporting (starting with NASA-5)
MSD021 SSAS/GSC	Toxicological Assessment of Airborne Volatile Compounds	Air sampling - into a solid sorbent air sampler (SSAS - 24 hours); and - grab sampler container (GSC)
Defib	Defibrillator and *Mir* Medical Restraint System	defibrillator checkout CMRS checkout
MSD011	Nutritional Status Evaluation	- completion of questionnaire on meal frequency - TLM questionnaire data downlink - body mass measurement (for MK-6)
MSD008	In-Flight Orthostatic Tolerance Testing	During the Russian LBNP test the astronaut uses the ABPM monitor; approximately every minute entries are made in the SMP log of the heart rate, arterial pressure, Chibis pressure
MSD008	Physical Fitness Assessment	- PT recording in a log following every session - use of HRM to monitor heart rate during PT - weekly download of HRM onto MIPS - graded effort test on cycle
	Special *Mir* Environment Evaluation	- collection of condensate samples (into U.S. samplers) - CPA reading Contingency - air sampling for ethylene glycol Contingency - free water collection
MSD084 (MAD)	*Mir* Acoustic Noise Measurements	24-hr acoustic measurements in *Mir* modules and by crew members
MSD071	In-Flight Holter	Daily Monitoring (24 hr.)
MSD085	Neurocognitive Assessment	Completion of short version of SCAT on MIPS

SMP Research *Mir*-21/NASA-2

Experiment	Planned	Completed	Notes
MO-1 Private Medical Conferences	first 7 days - daily weekly after that	first 7 days - daily weekly after that + additional PMC*	* At the request of the NASA surgeon because of IMMUNITY experiment
MO-9 Physical	chemical blood analysis using PSBA monthly (Days 30, 60, 90, 120) or for medical reasons	04/18/98 not performed* 05/08/96** 06/19/96***	*PSBA not found **BTS PSBA used *** PSBA cartridges were not stored in a refrigerator causing the data to be compromised and the experiment to be canceled
M-10 Urine Sample Analysis	Once a month	04/09, 05/05, 06/05, 07/02, 08/02/96 Monthly until August (in conjunction with MK-27), subsequently not performed*	*As recommended by the NASA surgeon because MO-10 results were identical to MK-27 results
MO-11 Radiation Level Data Upload from TEPC	Once biweekly	performed monthly* 04/02, 16, 05/14, 06/18, 07/23, 08/27/96	*As recommended by NASA CG
MO-12 Radiation Monitoring	Continuous monitoring	Continuous monitoring 03/31 - 09/25/96	Completed
MO-14 Environmental Health Anomalies	Monthly	Monthly 04/30-05/01, 05/20-21, 06/19-20, 06/27-28, 07/17-18	Completed
MO-8 Record of MSMK Pharmaceutical Intake	Performed as needed	Performed using an alternative method - entry in MSMK log	Completed
MO-2 Download of General MSMK Utilization Data from Bar Code Reader	Once biweekly	No work was performed	MIPS downlink was not available: the cable required to download data from bar code reader to MIPS could not be located

SMP Research *Mir*-22/NASA-3

Experiment	Planned	Completed	Notes
MO-1 Private Medical Conferences	first 7 days - daily weekly after that	first 7 days - daily weekly after that	Completed
MO-9 Physical	monthly or for medical reasons	Monthly 10/14, 11/19, 12/13/96	Completed
M-10 Urine Sample Analysis	Once a month	Monthly - early into the flight (in conjunction with MK-27) 10/10, 11/11/96, subsequently not performed*	*As recommended by NASA surgeon since MO-10 results are identical to those of MK-27
MO-11 Radiation Level Data Upload from TEPC	MIPS download - monthly, display reporting - weekly	Downloads: 10/3-4, 10/21-22; 11/20-21/96, 01/10-11/97 display reporting - weekly	Completed
MO-12 Radiation Monitoring	Continuous monitoring	Continuous monitoring 09/25/96 - 01/16/97	Completed
MO-14 Environmental Health Anomalies	Monthly	Monthly 09/26-27, 10/7-8, 11/15-16, 12/15-16/96, 01/7-8/97	Completed
MO-8 Record of MSMK Pharmaceutical Intake	Performed as needed	Performed as needed.	
MO-2 Download of General MSMK Utilization Data from Bar Code Reader	Monthly or for medical reasons	10/4/96 11/15/96 12/16/96*	Corrupt data received in all downloads
MO-6 CSST	Weekly	Weekly	Completed

SMP Research *Mir*-23/NASA-4

Experiment	Planned	Completed	Notes
MO-1 Private Medical Conferences	first 7 days - daily weekly after that	first 7 days - daily then once a week	
MO-9 Physical	monthly or for medical reasons	02/06/97 - incorrect data received, subsequently not performed	Portable Blood analyzer (PCBA) software incompatible with delivered cartridges
M-10 Urine Sample Analysis	Once a month	Survey not performed	As recommended by NASA surgeon. Astronaut performed MK-27
MO-11 Radiation Data Download from TEPC	MIPS download - monthly, display reporting - weekly	Download monthly: 02/13-14, 03/19-20, 04/17-18, 05/14-15/97 voice reporting - weekly	Completed
MO-12 Radiation Monitoring	Continuous monitoring	Continuous monitoring 01/16/97 - 05/19/97	Completed
MO-14 Environmental Health Anomalies	Monthly	Monthly: 01/23-24; 02/20-21*; 04/16-17; 05/12-13/97 Additionally: 02/23/97	No research was performed in March since all the formaldehyde monitors were used up during the *Mir* fire. Operations continued following delivery of new hardware aboard Progress.
MO-8 Record of MSMK Pharmaceutical Intake	Performed as needed	Performed as needed	
MO-2 Installation of Coded BDL Software		01/23/97	Completed
MO-2 Download of General MSMK Utilization Data from Bar Code Reader	Monthly or for medical reasons	02/14; 03/25/97*	Both the files contained corrupt data
MO-6 CSST	Weekly	Weekly	Completed
Archive Water Sample Analysis	Condensate sampling - 2 sessions Water sampling prior to and after MFU replacement, during mated flight (3 sessions)	Condensate sampling - 3 sessions: 02/1-4, 05/13-16, 05/16-19/97 Water sampling - 3 sessions: 01/18, 01/30, 05/05/97	Completed

Appendix 6 Cont.

Experiment	Planned	Completed	Notes
MSD021 Crew Microbial Assessment	Monthly, NASA Astronaut	3 sessions - NASA Astronaut: 01/30, 03/05, 05/05/97* One session each per *Mir* crew member	* Not performed in April since 2 kits were used by mistake in the course of the first session (cosmonaut samples were taken)
MSD021 *Mir* Microbial Assessment	Monthly, air and surface sampling	Monthly: 01/18, 01/30, 03/05, 04/01, 05/05/97	Completed
MSD021 Toxicological Assessment of Airborne Volatile Compounds	SSAS sampling - 5 sessions GSC sampling - 4 sessions	SSAS sampling: 01/21-22, 02/12-13 (02/23-24/97*), subsequently not performed* GSC sampling: 01/21, 02/12, (02/23-24*), 04/16, 05/12/97	On 02/23-24/97 because of the *Mir* contingency the NASA flight engineer decided to use up all SSAS and GSC to evaluate the dynamic of the condition of the station's atmosphere. Additional samplers (GSC only) were delivered by Progress following which the experiment was continued.

SMP Research *Mir*-23/NASA-5

Appendix 7

Name of monitoring activity	Planned	Implemented	Comments
MO-1 Private medical conferences	first 7 days - daily, then - once a week	first 7 days - daily, then - once a week	Completed
MO-9 Physical examination	once a month or per medical indications	6/13/97	* Completed
MO-10 Urine sample analysis	once a month	was not conducted	Per NASA flight surgeon recommendation. Astronaut completed MK-27 (Biochemical study of urine)
MO-11 Radiation data download from TEPC hardware	MIPS loading - once a month display data download - once a week	Loading: 6/8-9/97 voice downlink - weekly	* Completed
MO-12 Radiation monitoring	Continuous monitoring	Continuous monitoring 5/19/97 - 10/3/97	* 12 dosimeters out of 18, since 6 dosimeters remained in Spektr
MO-14 Environmental Health Anomalies	5 sessions	2 sessions 5/29-30/97, 6/18-19/97	* Completed
MO-8 Record of MSMK pharmaceutical intake	Performed as needed		*
MO-2 Download and downlink of total General (MSMK) utilization data from Bar Code Reader	once a month or per medical indications		* Completed
MO-6 CSST Name changed as of NASA-5: Assessment of Crew Psychological Condition and Effectiveness of Psychological Support Measures	once a week	once a week til August**	** Was not conducted after that - astronaut's request

Appendix 7 Cont.

Name of monitoring activity	Planned	Implemented	Comments
Water archive sample test	Condensation sample collection - 2 sessions - Water sample collection during the docked period, before and after Purification Column Unit (БКО) replacement (3 sessions)	- Condensation collection - 2 sessions: 5/20/97**, 8/4-7/97 - Water sample collection - 1 session during the docked period 5/19/97	* ** Out of two Potable Water Tanks (ЕДВ) there were taken samples of atmospheric humidity condensate (КАВ) which was collected at the time of ethylene glycol leaks
MSD021 Crew microbial assessment	once a month of NASA astronaut and cosmonauts	1 session for each crew member	*
MSD021 *Mir* microbial assessment	once a month	2 sessions 5/18/97, 5/28/97 (surface) 6/2/97 (air)	*
MSD021 Toxicological assessment of volatile organic compounds in the atmosphere	SSAS sample collection - 5 sessions GSC sample collection - 4 sessions	SSAS sample collection - 2 sessions: 5/29-30/97, 6/18-19/07 GSC sample collection - 1 session: 6/18/97	*
Defibrillator and *Mir* Medical Restraint System	defibrillator checkout - once in 45 days CMRS checkout - one time	defibrillator checkout - 5/24/97, 8/5/97 CMRS checkout - 6/3/97	
CPA readings	Every 5 days	Every 5 days with an interval from 7/3/97 to 7/24/97**	** Due to a limited battery charge
Air sample ethylenglycol test	If required	6/9/97, 6/16/97, 6/23/97, 6/30/97, 7/24/97, 7/30/97, 8/4/97, 8/23/97, 9/1/97 - 9 sessions**	** Due to ethylene glycol leaks

* The studies were terminated because part of the hardware became unavailable due to the Spektr failure.

SMP Research *Mir*-24/NASA-6

Appendix 8

Name of monitoring activity	Planned	Implemented	Comments
MO-1 Private medical conferences	first 7 days - daily, then - once a week	first 7 days - daily, then - once a week	Completed
MO-9 Physical	once a month or per medical indications	(11/13/97, 12/21/97)*	*Form 020 report on health status. Blood test from PCBA was not conducted, because cartridges were stored in БХ-2 where temperature exceeded +8°C
MO-11 Radiation data download from TEPC	MIPS loading - once a month display data download - once a week	Loading - once a month 10/9-10/97, 11/13-14/97, 12/22-23/97 + 12/30/97*, 01/21-22/98 voice downlink - weekly	TEPC replacement - 9/30/97 * Due to TEPC transfer back to PRIRODA. From 12/23/97 to 12/30/97 it was located in the KRISTALL module
MO-12 Radiation monitoring	Continuous monitoring	Continuous monitoring 10/3/97 - 1/27/98	Completed
MO-14 Environmental Health Anomalies	5 sessions	5 sessions 10/13-14/97, 10/30-31/97, 11/20-21/97, 12/18-19/97, 1/12-13/97	Completed
MO-6 CSST Name changed as of NASA-5: Assessment of Crew Psychological Condition and Effectiveness of Psychological Support Measures	once a week	once a week till 1/3/98	* Was not conducted after that - astronaut's request
Archive Water Sample Analysis	Condensation sample collection (into Russian sample collectors) - 2 sessions 1 session - water sample collection during the docked period	- Condensation collection - 3 sessions: 11/13-17/97, 1/16-19, 25-28/98 - Water sample collection - 1 session during the docked period 10/1/97	Completed
MSD021 *Mir* microbial assessment	3 sessions of water collection (before, after multifiltration unit (БКО) replacement, at the end of the flight) 4 sessions of air and surface sample collection	Water collection - 3 sessions: 11/17/97, 11/27/97, 1/19/98 Air and surface samples - 4 sessions: 10/2/97, 10/22/97, 11/17/97, 1/2/98	Completed

Appendix 8 Cont.

Name of monitoring activity	Planned	Implemented	Comments
MSD021 Toxicological assessment of volatile organic compounds in the atmosphere	SSAS sample collection - 5 sessions GSC sample collection - 5 sessions	SSAS sample collection - 5 sessions: 10/13-14/97, 10/30-31/97, 11/20-21/97, 12/18-19/97, 1/12-13/98 GSC sample collection - 6 sessions: 10/30/97, 11/20/97, 12/18/97, 12/21/97*, 1/12/98, 1/24/98	* Additionally, due to Freon leak
Defibrillator and *Mir* Medical Restraint system	defibrillator checkout - once in 45 days CMRS checkout - one time	defibrillator checkout - 10/10/97, 1/22/98 CMRS checkout - 1/22/98	Completed
MSD011 Nutritional Status Assessment	Once a week	Once a week	Completed
MSD008 In-flight orthostatic tolerance test	two times during the flight (during Russian LBNP test - MK-4)	once during the flight (12/25/98)*	* MK-4 was conducted, astronaut did not find equipment to execute U.S. ABPM protocol
MSD008 Physical Fitness Assessment	- Daily - recording of the execution of physical exercises and heart rate monitoring during physical exercises - once a week - heart rate monitor data loading - once a month - graded cycle ergometer test	- Daily recording of the execution of physical exercises and heart rate monitoring during physical exercises from 10/4/97 (the 7th day) - Heart rate monitor data loading - weekly Graded cycle ergometer test 10/9/97, 12/2/97, 1/23/98*	* Was not conducted in November due to TM unavailability (Medical Support Team requirement)
Special assessment of *Mir* environment	- 4 sessions - Condensation sample collection (into U.S. sample collectors) - once in 5 days - CPA readings - For contingency situations - Air sample ethylenglycol test - For contingency situations - Free water collection	Condensation collection - 3 session: 11/27-28/97, 1/17-19, 26-28/98 CPA - every 5 days - 12/4/98* - 1/19/98	Upon IBMP request due to current heating loop activities

SMP Research *Mir* - 25/NASA - 7

Appendix 9

Name of Monitoring Activity	Planned	Implemented	Comments
MO-1 Private Medical Conferences	Daily during first 7 days, then weekly	Daily during first 7 days, then weekly	Closed
MO-9 Physical	Monthly, or following medical data	Monthly: 02/23, 03/12, 04/24, 05/26/98	Closed
MO-11 Radiation Data Download from TEPC	Monthly MIPS Inputs, Weekly Display Information Reports	Monthly Inputs: 02/10-11, 03/12-13, 04/23-24, 05/13-14, 05/28-29/98; Weekly Voice Downlink	Closed
MO-12 Radiation Level Monitoring	Continuous Monitoring	Continuous Monitoring since 01/27/98	Completed as planned
MO-14 Environment Health Anomalies	5 Sessions	5 Sessions: 02/5-6, 03/6-7, 03/27-28, 04/28-29, 05/25-26	Closed
MO-6 CSST	Weekly	Weekly	Closed
Archive Water Samples Analysis	2 Sessions - Condensate Sample Collection (in Russian Samplers) 1 Session - Waster Sample Collection in Mated Flight	Condensate Collection - 3 Sessions: 04/26, 05/08, 06/3-7/98 Water Sample Collection - 2 Sessions in Mated Flight 01/26, 06/07/98	*STS-89 and STS-91
MSD021 *Mir* Microbial Assessment	3 Sessions of Water Collection (Before and after Multifiltration Unit Replacement, at the end of flight) 5 Sessions of Air and Interior Surface Sample Collection	Water Collection - 3 Sessions: 0.4/09, 04/23, 05/21/98. Air and Interior Surface Samples - 5 sessions: 01/26, 03/05, 04/09, 05/20, 06/05/98.	Closed
MSD021 Toxicologic Assessment of Volatile Organic Compounds in the Atmosphere	SSAS Uses - 5 Sessions GSC Uses - 5 Sessions	SSAS Sampling - 5 Sessions: 02/5-6, 03/6-7, 03/27-28, 04/28, 29, 05/25-26/98 GSC Sampling - 7 Sessions: 02/28, *03/06, 03/27, 04/29, 05/25, 05/29, *06/04/98	* Additional sessions taken on recommendation of Consultants' Group

Appendix 9 Cont.

Name of Monitoring Activity	Planned	Implemented	Comments
Defibrillator and *Mir* Medical Restraint System	Defibrillator Checkout - Every 45 Days CMRS Checkout - once	Defibrillator Checkout - 02/06, 03/18, 04/30/98 CMRS Checkout - 02/24/98	Closed
MSD011 Nutritional Status Assessment	Weekly	Weekly	Closed
MSD008 In-Flight Orthostatic Tolerance Test	Daily - Exercise Registry and Pulse Rate Monitoring During Exercises Once a week - Pulse Rate Monitor Data Input Once a month - Ergometer Graded Load Test	- Exercise Data Recording and Pulse Rate Monitoring During Exercises daily from 01/31/98 (the 7th day) - Weekly Pulse Rate Monitor Data Input Ergometer Graded Load Test: 02/25, *05/18/98.	* Suspended in March and April at NASA flight surgeon's recommendation due to a large number of load samples taken under Russian Medical Operations Program
Special *Mir* Environment Assessment	- 2 Sessions - Condensate Sample Collection (in American Samplers) - Every 5 days - CPA Data Collection Air Samples for Ethylene Glycol at ONS Free Floating Water Collection at ONS	Condensate Collection - 3 Sessions: 04/27, 05/08, 06/3-7/98 CPA - Every 5 Days 02/24/98*	*In CTV at IMBP recommendation
MSD084 *Mir* Acoustic Noise Measurement	In Modules -2 Sessions in Each Module (12 Sessions) Crew Members -2 Sessions by Each Crew member	02/2-3, 4-5, 9-10, 23-24, 27-28; 03/6-7, 9-10, 12-13, 16-17, 20-21, 26-27; 03/31-04/01; 04/8-9, 13-14, 21-22, 27-28; 05/5-6, 13-14, 19-20/98	*The cosmonauts have not performed this research
MSD071 In-Flight Holter Monitoring	Every month	02/23-24, 04/24-25, 05/26-27/98	
MSD085 Neurocognitive Assessment	Every month	03/26, 04/25/98	

INFORMATION

Concerning Psychological Support of American Astronaut Missions on the *Mir*
Mir-NASA Program

Appendix 10

	Psychological Support Activities								Monitoring	
Mission	Parcels, Surprise Packages	Conferences With Relatives and Friends		TV and Radio	Packet and Radio Ham Comm	Radio News and Entertainment Program	News Program (daily)	Conferences With Consultant Group	Neuropsychological Status (daily)	Work and Rest Mode (daily)
		TV Sessions	Phone Convers.	Conferences With Guests						
NASA - 1 Thagard	1	3	5	3		5	+	+	+	+
NASA -2 Lucid	3	8	17	13	+	8	+	+	+	+
NASA - 3 Blaha	2	5	10	7	+	7	+	+	+	+
NASA - 4 Linenger	1	3	14	5	+	6	+	+	+	+
NASA - 5 Foale	2	2	14	12	+	28	24	+	+	+
NASA - 6 Wolf	1	6	13	9	+	19	24	+	+	+
NASA - 7 Thomas	1	5	9	13	+	7	+	+	+	+

NASA 6 astronaut David Wolf and NASA 7 astronaut Andy Thomas during a handover session

Section 10 - Crew Operations on *Mir*

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10.1. Introduction

Continuous habitation and operations of NASA astronauts onboard the *Mir* began with the docking of Shuttle STS-76 on 24 March 1996. Beginning at that time, international crews consisting of two Russian cosmonauts and one American astronaut worked on board the *Mir* station.

One of the features of the *Mir*/NASA program was connected with the procedure of rotating astronauts to the *Mir*. After the first NASA astronaut, Norman Thagard, the rotation of astronauts utilized the Shuttle spacecraft, which docked with the *Mir* docking module (DM). Shannon Lucid, the NASA-2 mission astronaut, performed the first long-duration flight under the *Mir*-NASA program. She was delivered to the *Mir* station on 24 March 1996 to join the *Mir*-21 crew working on the complex. Later, there were five more successful missions (NASA-3, NASA-4, NASA-5, NASA-6, and NASA-7). Seven Shuttle dockings with the *Mir* were performed during this time to complete American-Russian transport operations. The program of NASA astronaut stays on the *Mir* complex ended on June 8, 1998, after the undocking of the *Mir* complex and Shuttle STS-91. The total of 7 astronauts participated in the long-duration missions on board the *Mir* within the framework of *Mir*-Shuttle, *Mir*-NASA programs; 3 of them as cosmonaut researchers, 4 astronauts as *Mir* flight engineers-2. U.S. astronauts worked on orbit together with members of 6 Russian main expeditions: *Mir*-18, *Mir*-21, *Mir*-22, *Mir*-23, *Mir*-24, and *Mir*-25.

10.2. Joint Activities of *Mir* and Shuttle Crews

Joint activities of astronauts and cosmonauts while on orbit were determined by mission plans for *Mir*, Soyuz TM, Progress M, Shuttle, and documents developed by several WGs.

The results of this activity are presented in corresponding sections of this report.

Crew joint activity began the moment communications were established between the *Mir* and the Shuttle (approximately three hours prior to docking). From that moment the crews worked from a common flight data file, which included a joint timeline and joint flight procedures.

During the mated flight of the Shuttle and the *Mir* there was a wide range of joint operations including:

- exchanging seat liners and personal equipment of astronauts in the Soyuz vehicle;
- transferring Russian and American cargo from the Shuttle to the *Mir* to re-equip and repair onboard systems and hardware for scientific research and to supply the crew with food and water;
- transferring Russian, American, and European Space Agency cargo from the station to the Shuttle for subsequent return to Earth;
- completing a line of experiments aimed at decreasing the risks in assembling the International Space Station (ISS);

- holding joint press conferences and other symbolic activities;
- joint planning of crew activities on the *Mir*-Shuttle complex.

After undocking, the Shuttles performed a fly-around of the station and conducted still and video-photography of the *Mir* complex exterior surfaces which included the goal of detecting the leak site on the Spektr module during flights STS-86, -89, and -91.

10.3. NASA Astronaut Crew Transfers

During *Mir*-Shuttle mated operations, flight crew transfer occurred between the astronaut that was completing his flight and the astronaut that was arriving on the complex. In their postflight reports, the NASA astronauts noted that the crew transfer was a very important process and the successful completion of the flight program might depend upon the proper organization of the transfer. With the goal of ensuring a rapid adaptation by the astronaut arriving on the complex, it is advisable to create a single procedure for all astronauts and include in it the following steps:

- correction of the flight data file in accordance with the actual condition of the scientific equipment;
- psychological support for the astronaut arriving on the complex (above all, render assistance in psychologically adjusting to extended flight);
- render assistance when using amateur radio communications;
- prepare scientific equipment and hardware for transfer (clear placement of scientific equipment according to predetermined storage locations, marking the hardware and lockers);
- filling out log books for hardware and the electronic version of the inventory taking into account the actual condition and location of scientific equipment and hardware;
- instruct the arriving astronaut about the following issues:
  * assuring crew safety;
  * placement of scientific equipment and hardware;
  * changes that took place during the flight to the scientific equipment and the astronaut's activity algorithm in operating and servicing the scientific equipment;
  * demonstrating how to perform individual scientific experiments and the procedures for placing the scientific equipment into its initial state;
  * explaining and demonstrating how to perform daily procedures and servicing of the complex's onboard systems in accordance with the duties assigned to the astronaut.

As experience has shown, taking these steps allows the arriving astronaut to partially adapt to these issues and to begin to work independently within four-five days of flight. Complete adaptation occurs after approximately three weeks of operations on the complex.

In planning the handover it is necessary to consider that it is more difficult for the American astronaut to complete the handover than the Russian crew. The Russian crew has both the commander and the flight engineer involved. The

American astronaut has to complete his handover alone.

In the first flights under the *Mir*/NASA program the astronauts noted a lack of time allocated for crew handover. In the future, the planning situation will be significantly improved, however all of the astronaut's free time is devoted to handover.

10.4. Accomplishments

While completing the *Mir*/NASA program, the astronauts onboard the *Mir* complex completed the following tasks during their work:

- acquisition of experience in extended operations by astronauts on board the station;
- performance of scientific research and experiments in various disciplines;
- refining the interaction between the partners in the joint space program.

10.5. Objectives

The primary objectives of the scientific program were:

- obtaining technical and procedural experience in performing scientific research in the conditions on the orbital space station;
- studying the *Mir* complex environment concerning microgravity conditions and performing experiments in fundamental biology, studying microgravity, and Earth observations from space;
- performing experiments which demonstrate selected technology and hardware, to confirm ISS designs and procedures;

10.6. Crew Responsibilities

Practically all parts of the scientific research and experiments were completed by NASA astronauts. Russian cosmonauts were required to participate in cases where NASA hardware interfaced with the *Mir* complex and to render the necessary assistance when performing experiments and during off-nominal situations.

We learned from experience that the level of actual participation of Russian cosmonauts was larger than was identified in the program documentation, especially when contingency situations with scientific equipment occurred.

In addition to the research duties, the NASA astronauts rendered assistance in operating individual systems on the complex, provided EVA support inside the complex, and participated in three extravehicular activities (EVAs) with Russian cosmonauts.

NASA astronaut - *Mir* Mission flight engineer-2 responsibilities included:

- to implement scientific experiment and research program;

- to inventory their scientific program hardware;
- to conduct crew handover;
- to participate in cargo transfer operations;
- to perform housekeeping operations on board *Mir* (cleaning, preventive measures);
- to maintain own life support and ability to work;
- to communicate with Mission Control (MCC);
- to provide TV reports, videorecording and photography;
- to utilize life support systems in nominal modes;
- to participate in maintenance activities;
- to perform EVA if it is planned in the mission program;
- to perform activities to recover from contingency situations.

Some of the NASA astronauts noted in their postflight reports that during spaceflight they did not consider themselves to be a full-fledged flight engineer since in the operations plan only scientific experiments were prescribed for them. In the astronauts' opinion, they could and should be able to perform many standard duties of the flight engineer. This would decrease the workload on the Russian cosmonauts and allow the American astronauts to acquire experience operating the *Mir*'s service systems and to improve the crew interaction system. For this it was necessary to define a specific list of flight procedures which the American astronaut would complete and would be thoroughly trained in on Earth and planned for in the daily operations plan.

Such procedures could include:

- activating/deactivating the Elektron-V system;
- standard operating of the trace contaminants filtering unit (БМП) and the Vozdukh atmospheric purification systems (СОА);
- receiving radiograms via packet-type communications, etc.

This list could be increased as experience is acquired by the American astronauts. In connection with this, the NASA astronauts noted that during the final astronaut training stage for spaceflight it is necessary to increase the number of training sessions with the Crew Commander observing the astronaut's operating and servicing onboard systems so that the Crew Commander can make an objective evaluation of the astronaut's level of professional training. In reality, the astronaut was forced to prove his professional training to complete duties in operating and servicing the complex's onboard service systems to the Russian cosmonauts in flight.

10.7. EVA Operations

While Russian cosmonauts were performing EVA, the NASA astronaut was responsible for supporting them inside the *Mir* complex. Among these duties were:

- issuing commands from the Simvol consoles and equipment;
- still and video photography of the EVA process;

- working with the communications equipment

For various reasons, not all of the NASA astronauts received the same training in EVA support. Therefore additional in-flight training was required for several of them (Shannon Lucid, David Wolf, and Andrew Thomas).

During the supplemental in-flight training of the astronauts, the following issues were covered:

- sequence of interacting with the cosmonauts working in open space (which communications systems are used and the order of use);
- knowledge of the list of commands given by the astronaut inside the station (which consoles are used and the sequence for working with these consoles);
- off-nominal situations and the actions to recover from them jointly with the other crew members.

While completing the *Mir*/NASA program the NASA astronauts, as part of the Russian-American crews, completed three EVAs in open space from the *Mir* complex. Information on the EVAs is presented in Table 10.1.

EVAs in Open Space From the *Mir* Complex

Table 10.1

№	EVA crew	EVA date	EVA length (hrs)	Primary tasks of the EVA
1	V.V. Tsibliev J. Linenger (USA) (*Mir*-23)	04/28/97	4:58	Installation of the optical properties monitor (OPM) on the DM. Installation of the Benton dosimeter on the pressurized-scientific compartment (ПНО) of Kvant-2. Disassembly of the PIE, MSRE scientific equipment from the special airlock module (ПСО).
2.	A.Ya. Solovyev M. Foale (USA) (*Mir*-24)	09/06/97	6:00	Inspection of the depressurized Spektr module's exterior surface. Inspection of the external cooling radiator (HXP) panel. (External cooling radiator panel mounting brackets № 111and 113 were broken, and №. 110 and 112 were bent. In the area where the VSTI was opened no visible damage was detected). A special gauge was used to measure the circular gap around the SA-2 drive unit. (The gap was uneven. The gauge moved freely on the unpressurized module (НГО) side, and did not move on the docking assembly side). Securing the handrail package near the "Miras" equipment on the unpressurized module. Rotating SA-4 and supplemental SA-4. Disassembling the Benton dosimeter from the Kvant-2 instrument-scientific compartment.
3	A.Ya. Solovyev D. Wolf (*Mir*-24)	01/14-15/98	3:52	Egress from the instrument-scientific module. Inspect the egress hatch, detect risks of catching on the locks). Take measurements with the space portable spectral reflectometer on the exterior surface of the pressurized-cargo compartment-1. Make a TV report near the egress hatch about D. Wolf's first EVA. Close the egress hatch using primary and reserve locks (the special airlock module is not pressurized. Air-locking operations in the instrument-scientific compartment).

10.8. Interactions of the Russian-American Crews With the Main Real-Time Operations Management Group and the NASA Consultant Group at MCC-M

Planning operations and controlling the joint Russian-American crew was performed by the MCC Main Real-Time Operations Management Group and the NASA Consultant Group.

In the crews' opinion, during the initial stage of NASA astronauts' operations on the *Mir* complex there were not adequate interactions between the NASA Consultant Group and the Main Real-Time Operations Management Group which created problems when organizing crew operations. The NASA Consultant Group frequently changed the astronauts' work program and did not make the Main Real-Time Operations Management Group and the Crew Commander aware of the change. This was noted in the postflight reports of the *Mir*-21 and *Mir*-22 crew. When organizing the interaction for the international crew, problems were encountered connected, apparently, with other stereotypical activities of American astronauts during flight on the Shuttle. This relates to the peculiarities of transmitting information to the crew, the distribution of responsibilities in maintaining vital functions, and others. There were occasions when changes to the current day's program were made independently and were not agreed to by the Crew Commander. The astronaut was given directions for these changes by the American Consultant Group. After approximately a month of joint flight, these shortcomings were mostly eliminated. This situation was repeated when the NASA Consultant Group at MCC changed. In the future, based on the experience acquired in planning joint operations and in refining the interaction plans between the Main Real-Time Operations Management Group and the NASA Consultant Group, these problems, to a significant degree, will not exist. The crews noted that there was no loss of information at MCC and the crew members sufficiently informed each other about all issues discussed following each communications session.

However, [illegible] the NASA astronauts and the Russian cosmonauts noted the necessity to improve planning and organizing radio exchanges on the "Crew-Main Real-Time Operations Management Group" channel. It is necessary to continue work to improve equipment and procedures for exchanging information using packet communications and to automate the process as much as possible, ensuring minimal crew participation in completing the procedures;

A significant number of radiograms under the NASA program contributed to a heavy load on the "MCC-*Mir*" channel. Russian cosmonauts in their postflight reports noted that the inadequate monitoring by the Main Real-Time Operations Management Group of the content of these radiograms led to conditions where information was received on board that was not flight critical (personal letters and secondary questions on American experiments) at the same time that radiograms containing operation information competed for time.

10.9. Conclusions and Recommendations

1. During the course of NASA astronaut operations as part of the *Mir* complex crew, the main objectives of the *Mir*/NASA program were completed. Positive experience was gained in extended operations by astronauts on board the space station, in performing scientific research and experiments, interaction of Russian-American crews with each other and with the ground personnel of the Main Real-Time Operations Management Group and the NASA Consultant Group at MCC-M.

2. *Mir*-Shuttle, *Mir*-NASA program implementation allowed U.S. astronauts and Russian cosmonauts to acquire experience of joint operation onboard the *Mir* and the Space Shuttle which will be further used on the ISS.

3. Cosmonaut and astronaut interaction has been developed during utilization of the *Mir* onboard systems including contingency situations.

4. Experience has been acquired on how to jointly implement scientific programs including contingency operation of scientific equipment. Cosmonaut and astronaut functions during the execution of the scientific program have been updated.

5. Development and tests of Russian crew operation support means on board the *Mir* have been continued and the American COSS (crew on-orbit support system) has been tested.

6. The U.S. inventory control system which is planned to be used on ISS has been further developed.

7. We learned from our joint operation experience that, to ensure quality and efficient operation on orbit, a deeper knowledge of the operational language is needed.

8. The experience acquired during implementation of the *Mir*/NASA program will be useful when training and completing spaceflights under the ISS program.

Mir cosmonauts Budarin and Solovyev

NASA 2 astronaut Shannon Lucid

Section 11 - Science Program

Authors:

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11.1 Introduction

11.1.1Rules and Responsibilities

11.1.1.1 U.S. and Russian

The relationship between the parties for the purposes of research program implementation was governed by US/R-001.

The primary document describing the scope of the team's work within each increment was the Increment Payloads Requirements Document (IPRD) developed by the MSWG-4.

Based on the above documents the U.S. party undertook:

- to develop the flight, training, and test hardware as well as the relevant operating and test documents;
- to formulate the program and the requirements as to the performance of each of the experiments;
- to ensure hardware testing;
- to develop drawings and electrical diagrams;
- to train the crew at NASA centers;
- to develop the experiment procedures;
- to secure concurrence as to the flight data files;
- to participate in the testing of the hardware in Russia;
- to participate in the experiment planning;
- to deliver the hardware to the station aboard the Orbiter.

The Russian party provided for:

- a feasibility assessment of the proposed program;
- the concurrence of hardware documents;
- hardware integration to the station systems;
- participation in acceptance testing (AT) and the incoming inspection of the hardware in the United States;
- the logistics of the AT and incoming inspection in Russia;
- the development of the flight data files;
- crew training in Russia;
- the collection of pre- and postflight data in Russia;
- experiment planning and in-flight implementation;
- data acquisition aboard and transmission from the station;
- the delivery of the hardware to the station using the Progress and Soyuz vehicles.

The schedules for the data exchange and hardware deliveries were defined in Document US/R-002.

The Russian party's primary task was to evaluate the safety of the U.S. hardware with regard to its utilization aboard the *Mir* station.

Considering the commercial nature of the project, Russian experts were not involved in setting experiment objectives, experiment result analysis, or validity evaluations except as regards experiments to assess *Mir* parameters and those where Russian researchers were invited to participate by the U.S. party.

In addition, Russian experts performed pre- and postflight data collection in Russia.

11.1.1.2 WG-4 and WG-6

Science program activities were supported by two WGs:

- WG-4: Mission Science WG;
- WG-6; *Mir* Operations and Integration WG.

WG-4 concentrated on developing the science program and processing the results while WG-6 dealt with developing the hardware, the documentation, crew training, hardware testing and integration on board the station, in-flight research, and data acquisition.

Normally, all issues were discussed at joint team meetings held 4 times a year.

11.1.2 Resources

An extensive research program has been implemented in the course of 6 missions performed under Contract NAS15-10110.

To support the program the Russian party was to allocate considerable resources to accommodate the mass of U.S. cargoes (up to 2, 360 kg aboard the station at any one time), the power requirement (up to 2 kW average per day), and crew time (up to 70% of the U.S. astronaut's duty time and 30% of the Russian cosmonaut's duty time).

The actual program proposed by the U.S. party required less power (up to an average of 1.5 kW) and cosmonaut time (up to 17%) but exceeded the agreed-to mass limitations. In addition, the Russian party provided for the delivery of U.S. cargoes by Soyuz and Progress vehicles, which had not been a contract provision.

At the program development and implementation stages the parties worked together in the spirit of mutual understanding without resorting to undue formality, thereby promoting overall activity success.

11.1.3 Program Overview

On the whole the program has been completed, although there was a shortfall with regard to NASA-5 because of the accident on the Spektr module, postponement of NASA-6 experiments, and cancellation of a number of sessions for medical reasons. Nonetheless, results have been obtained in virtually all the planned experiments.

A number of steps taken by the parties to achieve a consensus on issues of experiment setup and implementation aboard a space vehicle were conducive to program completion.

It was early in the course of flights under the *Mir*-Shuttle program that the U.S. party recognized that it was impossible to run a rigid preplanned timeline to cover the entire duration of a long spaceflight and adopted the Russian method of design (preflight) and real-time (in-flight) planning.

This approach allowed the introduction of new sessions for the purposes of hardware repairs and recovery, adjustment of experiment procedures, change in operation times, etc.

In its own turn because of time constraints, the Russian party agreed to depart from the principle of having experiment procedures developed by Russian experts, which saved some time but reduced the scope of documentation monitoring by principal investigators.

Russian researchers that had an active role in experiment preparation and result assessment have obtained new data in space medicine, biology, and developed a number of systems to evaluate the station's operating parameters.

11.2 Mission Science Working Group (WG-4)

11.2.1 WG-4 History

The Mission Science Working Group (MSWG) was established in July 1992 as WG-4 in the overall joint Shuttle/*Mir* WG structure, following the U.S.-Russian agreement for expanded cooperation in human spaceflight. The initial agreement called for the flight of a Russian cosmonaut aboard the U.S. Space Shuttle, the flight of a U.S. astronaut aboard the Russian Space Station *Mir*, and the docking of the U.S. Space Shuttle with the Russian Space Station *Mir*. WG-4 was tasked to develop a cooperative science program, primarily in the Life Sciences, as part of these joint missions. The scope of the joint activities was expanded in November 1993 with the addition of four more long-duration flights of U.S. astronauts aboard *Mir* and up to nine additional Shuttle dockings with *Mir*. The U.S. would also provide life and microgravity science hardware to be installed in the Spektr and Priroda modules. The research program was expanded to include other science disciplines. In December 1995, two additional long-duration missions of U.S. astronauts aboard *Mir* were agreed to. WG-4 was given responsibility for developing and managing the science requirements of this expanded research program.

11.2.2 WG-4 Responsibilities

The MSWG had the primary overall responsibility for managing the research requirements in the Phase 1 program. Throughout preflight planning, in-flight operations, and postflight closeout, the MSWG was the intermediary interface between the experiment disciplines representing the requirements of the Principal Investigators (PIs) and the various experiment implementation organizations and processes. These included NASA Headquarters and the Program Office Management; Configuration Control Boards; the Training, Integration, and Operations groups; and the science discipline groups made up of payload developers. During the Phase 1 program, approximately 150 PIs were represented by seven research disciplines: Advanced Technology, Earth Sciences, Fundamental Biology, Human Life Science, International Space Station (ISS) Risk Mitigation, Microgravity, and Space Sciences. (See Attachment 11.2 for the list of PIs and associated investigations.)

As part of this process, the MSWG was responsible for ensuring science requirements are clearly defined and documented for implementation. This involved the development and management of requirements documents, such as the jointly agreed IPRD used during Phase 1B and the STS-71/Spacelab-*Mir* Mission Science Requirements Document, a U.S.-only document. Due to frequent changes in mission resource allocations and operational constraints, these documents were updated as appropriate through configuration controlled changes to the baselined science requirements. Mission Science had the responsibility to resolve any resource conflicts among the various disciplines and investigations, and during flight operations to actively participate in the replanning process.

The MSWG was also involved in various WG meetings and flight readiness activities. Periodic joint meetings with the investigator teams, including as appropriate, international partners in the mission research, were held to review the science requirements and their proposed implementation as defined in operations products, address mission critical issues, and establish working protocols. At the start of each mission, readiness reviews were held to discuss and resolve any science or operations problems that would potentially delay or impact the success of the mission.

In support of mission preparation and implementation, the MSWG also developed informational packages for release to the public through the NASA Public Affairs Office, press briefings, brochures, web sites, and symposia.

After flight, Mission Science had the responsibility for assessing the operational and science success of each mission and ensuring that the PIs reported on the results of the experiments. The science results were tracked through direct reporting from the PIs, at science symposia and through tracking the PIs' publications and public presentations.

11.2.3 WG-4 Structures and Processes

Throughout each increment, and across the Phase 1 program, Mission Science coordinated with the Discipline Leads to ensure successful implementation of the research objectives of the Phase 1 program and the objectives of each individual PI.

For each increment, a set of science requirements were entered into a computerized database, the Payload Integration Planning System (PIPS), and established through baselining of its product, the IPRD, at the *Mir* Operations and Integration Working Group (MOIWG) configuration control board. The U.S. requirements were then reviewed with Russian counterparts of both MSWG and MOIWG to assure that they were within resource constraints. Periodic revisions were distributed based on updates agreed upon during these joint meetings. The Final IPRD, usually released three months prior to the start of each increment, was then used as the guiding document for operations planning and real-time implementation.

The MOIWG also used the PIPS database for hardware management and used the IPRD in developing operations products for mission implementation. Whereas the MOIWG had increment specific teams dedicated to premission planning, real-time operations, and postmission closeout, the MSWG maintained a core team that worked throughout all aspects of the Phase 1 research program, both at the management and research discipline level. Mission Science coordinated with the MOIWG and supported mission implementation functions as part of the Houston Mission Control Center (MCC-H) Payload Operations Support Area (POSA) and the *Mir* Operations Support Team (MOST) or U.S. Consultants Group in the TsUP (Russian Mission Control Center) in Korolyov.

During real-time science implementation, replan requests (RR), generated by the discipline teams or operations implementation members, were written to document requested changes. Specialists in the POSA, composed of a science and operations team, evaluated the RRs for implementation feasibility. If these changes were outside the scope of the requirements documented in the Final IPRD, the RR was attached to a change request for disposition through the MOIWG configuration control board. The PIPS database was updated with approved change requests throughout the course of the mission. Approved changes were sent over to the TsUP and negotiated with the Russian side as changes to the Russian Final IPRD. Once successfully negotiated, the Form 24 (Russian Timeline) was updated with the requested inputs. At the end of the mission, the Final IPRD represented what was planned for implementation. The RR attachments plus the Final IPRD represented what was actually implemented.

11.2.4 Results Processing

The goal of work in research of the *Mir*-NASA Project scientific program was to perform operations to support and supply the American scientific research of the *Mir*-NASA Project.

The operational objectives were:

1. A scientific methodological examination of American research, including biomedical ethics issues.
2. Ground preparation and certification of equipment and hardware for flight research.
3. Pre- and postflight data collection as part of the biomedical research program.
4. Training and ground following of the flight portion of experiments.
5. Participation in the preparation and performance of fundamental biological research.
6. Supporting ground following of experiments by Russian specialists at MCC.

In contrast to the previous stage of Russian-American scientific cooperation under the *Mir*-Shuttle program, the microgravity, biomedical, and fundamental biological research programs included suggestions which had been selected by an independent U.S. peer review panel, and the Russian side became familiar with them after the selection.

The American proposals which had passed a scientific review were presented to the Russian side in the form of a list of experiments and brief information about the research process, the equipment used, and crew time requirements. During the course of discussions between the Russian and American specialists, the feasibility of conducting the experiments in space was evaluated and the possibilities for pre- and postflight examinations of Russian cosmonauts and American astronauts were agreed to. The Russian specialists suggested combining a number of research projects into a single procedure, which would allow resources and time to be saved and would simplify crew member training.

As a result of the discussions, the Russian and American sides came to the agreement that for each of the experiments co-executors would be appointed from the Russian side who would ensure following the experiments in all stages of their preparation and implementation. The co-executors would integrate the requirements of the Russian national science program with the American research to avoid duplication and obtain valid scientific results which might be used by the partners in accordance with the special agreements for each separately performed experiment.

The joint work of the Russian and American scientists frequently led to significant modification of the American proposals. It made the proposal more realistic and adaptable to crew activity conditions during extended spaceflight. On a number of the proposals, the American scientists backed away from their initial requirements or simplified them.

The Russian co-executors prepared and presented materials for the Russian Academy of Sciences Biomedical Ethics Commission. Members of the Commission performed a great deal of preliminary work in standardizing the techniques for evaluating the risk of conducting the research with the help of people from the American Biomedical Ethics Commission. A single form of informed consent for performing research involving humans was developed and agreed to, which is used when preparing materials for cosmonauts of both sides. As a result of the commission's work, biomedical and fundamental biological research programs for the *Mir*-NASA project missions were approved.

The results of the agreements were outlined in the IPRD, which was really almost the implementation plan for the science documents. The IPRD addressed the issues of training astronauts and cosmonauts, performing pre- and postflight sessions, and the plan for transferring hardware from the Shuttle to *Mir* and returning hardware and experiments materials. Flight sessions were also addressed in the IPRD.

The Russian specialists took part in training the Russian crew members during the familiarization sessions at Johnson Space Center (JSC), as well as at Star City. The Russian specialists took part in preparing the procedures for performing the experiment, which were the prototype for the documentation for teaching cosmonauts and implementing the experiments during flight. Participation in preparing the flight data files also included:

- writing instructions for operating hardware;
- making corrections to preliminary versions of the flight data files;
- confirming the flight-ready version of the flight data files.

Long-term and detailed planning of the research took place with the participation of the Russian specialists who were responsible for performing individual experiments and the members of the MCC medical group. In addition, they prepared radiograms on experiment procedures, held radio conversations with the crew before and during the experiment, and held consultations on repairing hardware (if necessary).

At this stage of performing the research, the Russian specialists interacted with the American specialists in the Consulting Group at MCC. During this interaction, the procedures for performing the experiments were refined and the programs were corrected if necessary. Reasons for decreasing the quantity of research while it was being performed were:

- hardware malfunctions;
- medical restrictions;
- Spektr module depressurization;
- rescheduling of *Mir* service operations.

Problems that arose were regularly discussed in teleconferences between the American and Russian specialists, with management and leading project specialists participating.

The involvement of Russian specialists in the pre- and postflight observations in various experiments was not uniform, as some of them participated in the materials analysis and processing of results obtained.

The Russian scientists took part in gathering background data. In a number of cases they fulfilled service functions, and in other experiments they took on the role of co-executors, taking part in processing and analyzing data obtained.

The observations of Russian cosmonauts were called for by experiments with identical procedures in the American and Russian science programs, and were performed by Russian specialists per the agreed-upon protocols.

The degree of participation by Russian scientists was determined by preliminary agreements reached at meetings of the Joint Working Group. The partners exchanged data on the research in accordance with agreements reached at meetings of Russian and American specialists.

The problems which arose during the course of the experiments were resolved quickly by the scientists with the cooperation of the MCC Consulting Group and Russian specialists responsible for planning.

11.2.5 WG-4 Accomplishments

The challenges to the successful completion of the Phase 1 research program during its relatively brief history are too numerous to list in this report. Among a few major ones are: the compressed development schedule; the two sides learning to work together; overcoming language barriers; the U.S. team learning the "culture" of long-duration spaceflight; and replanning of the research program in the face of significant and ever-changing operational constraints. With the representation of accomplishments listed in this section, it is clear that the Phase 1 research program has overcome these challenges, yielding a wealth of new information and, as always in scientific endeavors, raising many new questions. It will be several more years before the full scope of what was accomplished and learned can be fully appreciated.

The 10 long-duration *Mir* missions and 7 long-duration NASA missions, as well as the 9 Shuttle-*Mir* docking Shuttle missions, resulted in a wealth of station research experience, samples, data, and science return for the approximately 100 unique *Mir*-based investigations, representing approximately 150 investigators, that were conducted during the NASA-*Mir* Research Program. Seven U.S. astronauts and 17 Russian cosmonauts, three of whom were involved in two Phase 1 missions, participated in the long-duration research program. The actual number of investigations per research discipline is supplied in Table 11.1, some of which were flown over multiple increments.

Number of Long-Duration Investigations per Discipline

Table 11.1

Research Discipline	Research Increment						
	1	2	3	4	5	6	7
Advanced Technology		1	2			1	3
Earth Sciences		2	2	2	3	3	3
Fundamental Biology	1	3	2	4	5	1	
Human Life Sciences	26	11	12	8	6	5	6
ISS Risk Mitigation		5	7	8	7	6	2
Microgravity	1	12	10	11	9	9	8
Space Sciences		2	2	2			
Total Investigations	28	26	37	35	30	25	22

Reference Attach. 11.3 for the table of investigations flown on each Phase 1 increment.

The *Mir* station provided many U.S. investigators, whose previous experiences included only short-duration Shuttle missions, their first experience with a long-duration platform as a test bed for facilities and experiment protocols planned for use on ISS. International participation in the Phase 1 research program included investigators from the United States, Russia, Canada, the United Kingdom, Japan, Germany, France, and Hungary.

Advanced Technology investigators used the weightless environment of *Mir* to study basic physical processes and generate better quality and new alloys, with multiple industrial and scientific applications.

The three-year near-continuous observations of Earth phenomena by trained crew members has added tens of thousands of images to the exciting database of Earth imagery and to researchers' understanding of long-term changes, both ephemeral natural and human induced, and for the first time documented global baseline conditions leading up to and through the 1997 El Niño.

Documentation during this timeframe on *Mir* demonstrated for the first time the northwestward drift of the South Atlantic Anomaly through comparison between Skylab and *Mir* data.

Fundamental Biology investigations yielded highly successful plant growth experiments resulting in the most biomass ever grown in space and the first plants grown from seeds developed entirely in space.

The Human Life Sciences study of crew members before, during, and after long-duration flight has led to a better understanding of the physiological and psychological effects of long-duration spaceflight. The NASA-*Mir* program has seen the documentation of space-induced changes in human body systems such as the immune system, cardiac functions, circadian rhythms, renal functions, and bone and mineral metabolism.

Mir operations and risk mitigation experiments have contributed significantly to our understanding of long-duration spaceflight and resulted in modifications to ISS planning, design, and operations. The structural dynamics and micrometeoroid impact experiments are two examples of demonstrations of crew and vehicle microgravity disturbances and interactions as well as how materials and structures respond to long exposures to the low Earth orbit environment.

Microgravity discipline supported science has extended the duration of tissue culture experiments from 14 days to 4 months in orbit developing 3-dimensional tissue cultures. Tissue constructs such as these are difficult to generate on Earth and have great potential for applications in orthopedic and cosmetic surgery. In addition, new techniques for growing protein crystals in space have been established with qualitative and quantitative improvements over ground-based activities. Analyses of these high-quality crystals are leading to advances in pharmacology and molecular biology.

The discovery of extraterrestrial particulates in the aerogels contained in the Space Sciences experiment collector trays clearly demonstrates that many cosmic dust particles can be returned to Earth for physical and chemical analysis.

Following each Phase 1 mission, each U.S. PI was required to submit to Mission Science a postflight Operational Accomplishments Report (R+30 days), a Preliminary Research Report (R+180 days), and a Final Research Report (R+1 year), outlining their research status and preliminary conclusions. To date, a total of 237 postflight research reports have been received, archived, and distributed by Mission Science. Attachment 11.4 contains the table of contents for each document published to date of these reports. Also, many PIs have published their Phase 1 research findings in peer-reviewed publications, and these are listed in Attachment 11.5.

The MSWG has also organized Research Results Symposia in which investigators have participated by sharing data between similar research areas and presentation of results to date. These types of forums have supplied NASA management, the Phase 1 crew members, and the participants of the Phase 1 research program with the results and successes of the numerous experiments conducted during the program. The first symposium, held at JSC in August 1997, focused primarily on experiments from the NASA-2 and NASA-3 missions. The second meeting, held in April 1998 at Ames Research Center, focused mainly on the NASA-4 and -5 missions. A third symposium targeted for November 1998, at Marshall Space Flight Center, will close out those experiments conducted throughout the program and will focus on the NASA-6 and -7 missions. Two symposia proceedings packages, a compilation of 82 Phase 1 experiment presentations, have been distributed and the table of contents of these can be found in Attachment 11.6.

11.2.6 Lessons Learned

The 10 most important lessons learned from the Phase 1 Research Program are listed below. Clearly, many if not all will have application in the successful conduct of the research program on ISS.

1. **Develop and implement a realistic schedule from experiment solicitation to flight.**
The 2-year experiment solicitation-to-flight schedule for Phase 1 was inadequate to ensure proper definition and implementation of all selected experiments without significant challenges. The lack of early definition of the research had multiple impacts to proper implementation of the experiments.

2. **Plan for a realistic complement of experiments for each long-duration mission to achieve specific scientific objectives.**
Provide a narrower focus for each increment and plan the research program accordingly (quality vs. quantity).

3. **Maintain clear distinction between science requirements (PI-generated) and science operations (guided by operational constraints).**
Science "requirements" were often changed to accommodate operational constraints; in truth, the requirements did not change, only their implementation.

4. **Ensure full coordination between experiments and facilities, hardware and software interfaces, in ground testing, training, etc.**
There were instances where incompatibilities were uncovered only in flight; this was usually due to inadequate time for preflight preparation.

5. **Ensure that training is performed in full-up configuration, with all experiment components.**

There were instances where the first time a crew member did an end-to-end experiment session was on orbit.

6. **In scheduling science activities, all overhead must be accounted for.**

Performing a science session usually requires additional time that initially was not accounted for, potentially leading to crew overwork. These ancillary activities include, but are not limited to, on-orbit refresher training; search for and identification of all required hardware items; evolving crew familiarity with the experiment; experiment setup; experiment stow.

7. **Develop a single hardware manifest.**

There were multiple manifests maintained by different organizations, with different purposes and authorities, often leading to confusion.

8. **Develop a single hardware/safety documentation system for all payload carriers.**

Hardware developers were often swamped in submitting essentially the same information to different organizations in different formats.

9. **With limited voice communication with the crew, rely more on E-mail.**

In many cases, use of E-mail allows for more thorough communication between the crew member and the ground support team.

10. **Understand the cultural differences between short-duration and long-duration flight and their interactions.**

These are in the areas of training, operations, manifesting, etc. Many of these factors are not unique to *Mir*, but are a reflection of operating in a long-duration environment, regardless of the specific platform.

11. **During selection of experiment, the management team should pay special attention to reviewing of biomedical studies to maximize crew member acceptability.**

11.2.7 WG-4 Summary

The Phase 1 Research Program offered many U.S. investigators their first opportunity to conduct research in a long-duration environment. This invaluable experience gained not only by the investigators but also by the U.S. and Russian ground support teams, in addition to the actual scientific return from the program, will be a tremendous aid in conducting similar research on ISS. From a research perspective, Phase 1 was clearly a worthwhile endeavor.

List of Phase 1 Principal Investigators and Their Experiments

Attach. 11.2

Phase 1A

Metabolic Research:	**U.S. Investigator(s)**	**Russian Investigator(s)**
Fluid and Electrolyte Homeostasis and its Regulation	Helen Lane, Ph.D.	Anatoly Grigoriev, M.D.
Dynamics of Calcium Metabolism and Bone Tissue	Helen Lane, Ph.D.	V. Oganov, M.D., Ph.D. Irina Popova, Ph.D.
Renal Stone Risk Assessment	Peggy Whitson, Ph.D.	German Arzamozov, M.D. Sergey Kreavoy, M.D.
Metabolic Response to Exercise	Helen Lane, Ph.D.	Irina Popova, Ph.D.
Metabolism of Red Blood Cells	Helen Lane, Ph.D.	Svetlana Ivanova, Ph.D.
Red Blood Cell Mass and Survival	Helen Lane, Ph.D.	Svetlana Ivanova, Ph.D.
Physiologic Alterations and Pharmacokinetic Changes During Spaceflight	Lakshmi Putcha, Ph.D.	I. Goncharov, Ph.D.
Humoral Immunity	Clarence Sams, Ph.D.	Irina Konstantinova, M.D.
Viral Reactivation	Duane Pierson, Ph.D.	Irina Konstantinova, M.D.
Peripheral Mononuclear Cells	Clarence Sams, Ph.D.	Irina Konstantinova, M.D.
Cardiovascular and Pulmonary Research:		
Studies on Orthostatic Tolerance With the Use of LBNP	John Charles, Ph.D.	Valeriy Mikhaylov, M.D.
Studies of Mechanisms Underlying Orthostatic Intolerance Using Ambulatory Monitoring Baroflex Testing and Valsalva Maneuver	Janice Yelle, M.S. John Charles, Ph.D.	Valeriy Mikhaylov, M.D.
Maximal Aerobic Capacity Using Graded Bicycle Ergometry	Steven Siconolfi, Ph.D. Suzanne Fortney, Ph.D.	Valeriy Mikhaylov, M.D. Alexander Kotov, M.D.
Evaluation of Thermoregulation During Spaceflight	Suzanne Fortney, Ph.D.	Valeriy Mikhaylov, M.D.
Physiological Response During Descent of Space Shuttle	John Charles, Ph.D.	Valeriy Mikhaylov, M.D.
Neurosensory Research:		
Evaluation of Skeletal Muscle Performance & Characteristics	Steven Siconolfi, Ph.D. John McCarthy, Ph.D.	Inessa Kozlovskaya, M.D. Yury Koryak, Ph.D. N.M. Kharitonov, Ph.D.
Morphological, Histochemical & Ultrastructural Characteristics of Skeletal Muscle	Daniel Feeback, Ph.D.	Boris Shenkman, Ph.D.
Eye-Head Coordination During Target Acquisition	M. Reschke, Ph.D. J. Bloomberg, Ph.D. W. Paloski, Ph.D.	I. Kozlovskaya, M.D. L. Kornilova, M.D. V. Barmin, M.D. A. Sokolov, M.D. B. Babayev, M.D.
Posture and Locomotion	J. Bloomberg, Ph.D. W. Paloski, Ph.D. M. Reschke, Ph.D. D. Harm, Ph.D.	I. Kozlovskaya, M.D. A. Voronov, Ph.D. I. Tchekirda, M.D. M. Borisov
Hygiene, Sanitation, and Radiation Research:		
Microbiology	Duane L. Pierson, Ph.D. Richard Sauer, P.E.	Natalia Novokova, Ph.D. Vladimir Skuratov, M.D.
In Flight Radiation Measurements	G.D. Badwhar, Ph.D.	Vladislav Petrov, Ph.D.
Measurement of Cytogenetic Effects of Space Radiation	T.C. Yang, Ph.D.	B. Fedorenko, Ph.D.
Trace Chemical Contamination	John James, Ph.D. Richard Sauer, P.E.	L. Mukhamedieva, M.D. Yuri Sinyak, Ph.D.

List of Phase 1 Principal Investigators and Their Experiments (continued)

Phase 1A continued

Behavior and Performance Research:		
The Effectiveness of Manual Control During Simulation of Flight Tasks (PILOT)	Deborah L. Harm, Ph.D.	V.P. Salnitskiy, Ph.D.
Fundamental Biology Research:	**U.S. Investigators**	**Russian Investigator**
Incubator	Biospeciman Sharing Program	T.S. Guryeva, Ph.D. Olga Dadasheva, Ph.D.
Greenhouse	Frank Salisbury, Ph.D. Gail Bingham, Ph.D.	M. A. Levinskikh, Ph.D.
Microgravity Research:		
Space Acceleration Measurement System (SAMS)	Richard DeLombard	S. Ryaboukha, Ph.D.
Protein Crystallization Methods	Stan Koszelac, Ph.D. Alexander Malkin, Ph.D.	O. Mitichkin, Ph.D.

Phase 1B

Advanced Technology:	**U.S. Investigator(s)**	**Russian Investigator(s)**
Optizone Liquid Phase Sintering	James Smith, Ph.D.	
Materials in Devices and Superconductors	Stephanie Wise Ruth Amundsen	Yuri Grigorashvili Svyatoslav Volkov Eugene Vasilyev Vladimir Koshelev
Commercial Protein Crystal Growth	Larry DeLucas	
Commercial Generic Bioprocessing Apparatus	Louis Stodieck	
Liquid Motion Experiment	Richard Knoll	
ASTROCULTURE	Raymond Bula	
X-Ray Detector Test	Larry DeLucas	
Earth Sciences:		
Calibration & Validation of Priroda Microwave Sensors	James Shiue, Ph.D.	Neon Armand, Ph.D.
Comparison of Atmospheric Chemistry Sensors on Priroda and American Satellites	Jack Kaye	
Regional & Temperature Variability of Primary Productivity in Ocean Shelf Waters	F.E. Muller-Karger O. Kopelevich	
Test Site Monitoring & Visual Earth Observations	Kamlesh Lulla, Ph.D. Cynthia Evans, Ph.D.	Lev Desinov, Ph.D.
Validation of Biosphere-Atmosphere Interchange Model for Northern Prairies	A. W. England Anatoly Shutko	
Validation of Priroda Rain Observations	Otto Thiele	
Fundamental Biology:		
Incubator-Integrated Quail Experiments on *Mir*	Gary W. Conrad, Ph.D. Cesar D. Fermin, Ph.D. Stephen B. Doty, Ph.D. Bernd Fritzsch, Ph.D. Patricia Y. Hester, Ph.D. Peter I. Lelkes, Ph.D. Page A. W. Anderson, M.D. Bernard C. Wentworth, Ph.D. Toru Shimizu, Ph.D.	Olga Dadasheva, Ph.D. Tamara Gurieva, Ph.D.

List of Phase 1 Principal Investigators and Their Experiments (continued)

Phase 1B continued

Fundamental Biology Continued:	**U.S. Investigators**	**Russian Investigators**
Environmental Radiation Measurements	Eugene Benton, Ph.D.	
Greenhouse-Integrated Plant Experiment	Frank Salisbury, Ph.D. Gail Bingham, Ph.D. John Carman, Ph.D. William Campbell, Ph.D. David Bubenheim, Ph.D. Boris Yendler, Ph.D.	M. Levinskikh, Ph.D.
Effective Dose Measurements	Sandor Derne, Ph.D.	Yuri Akatov
Cellular Mechanisms of Spaceflight Specific to Plants	Abraham. D. Krikorian	
Standard Interface Glovebox	Paul D. Savage	
Developmental Analysis of Seeds Grown on *Mir*	Mary Musgrave, Ph.D.	Margartia Levinskikh
Effects of Gravity on Insect Circadian Rhythmicity	T. Hoban-Higgins, Ph.D.	Alexei Alpatov
Active Dosimetry of Charged Particles	Jobst Ulrich Schott	
Human Life Sciences:		
Analysis of Volatile Organic Compounds on *Mir*	Peter Palmer, Ph.D.	Valentina Savina, M.D.
Anticipatory Postural Activity	Jacob Bloomberg, Ph.D.	Inessa Kozlovskaya, M.D.
Assessment of Humoral Immune Function	Clarence Sams, Ph.D.	A. T. Lesnyak
Bone Mineral Loss & Recovery	Linda Shackelford, M.D.	V. Oganov, M.D., Ph.D.
Collecting *Mir* Source & Reclaimed Waters	Richard L. Sauer, P.E.	Yuri Sinyak, Ph.D.
Crew Member & Crew-Ground Interactions	Nick A. Kanas, Ph.D.	Vyacheslav Salnitskiy
Evaluation of Skeletal Muscle Performance & Characteristics	S. F. Siconolfi, Ph.D.	Inessa Kozlovskaya, M.D.
Gas Analyzer System Metabolic Analysis Physiology	Floyd Booker	
Magnetic Resonance Imaging After Exposure to Microgravity	Adrian LeBlanc, Ph.D.	Inessa Kozlovskaya, M.D.
Microbiological Interaction in the *Mir* Space Environment	George M. Weinstock	A. Viktorov, Ph.D.
Protein Metabolism	T. Peter Stein, Ph.D.	Irina Larina, Ph.D.
Renal Stone Risk Assessment	Peggy Whitson, Ph.D.	Sergey Kreavoy, M.D. German Arzamazov, M.D.
Renal Stone Risk Assessment: Dried Urine Chemistry	Peggy Whitson, Ph.D.	Sergey Kreavoy, M.D.
Sleep Investigations	Allan Hobson, M.D. Timothy H. Monk, Ph.D. Harvey Moldofsky, M.D.	Irina Ponomareva, M.D.
Effects of Long-Duration Spaceflight on Eye, Head, & Trunk Coordination During Locomotion	Jacob Bloomberg, Ph.D.	Inessa Kozlovskaya, M.D.
Effects of Spaceflight on Gaze Control	Mill Reschke, Ph.D.	Inessa Kozlovskaya, M.D.
Frames of Reference for Sensorimotor Transformation	Alan Berthoz, Ph.D.	Victor Gurfinkel
Cardiovascular Investigations	C. Gunnar Blomqvist, M.D. Dwain Eckberg, M.D.	
International Space Station Risk Mitigation:		
Enhanced Dynamic Load Sensors on *Mir*	Sherwin Beck	
Mir Audible Noise Measurement	C. Parsons	
Mir Electric Field Characterization	Phong Ngo	
Mir Environmental Effects payload	Buck Gay	
Mir Wireless Network	Yuri Gawdiak	
Orbital Debris Collector	Freidrich Horz	
Passive Optical Sample Assembly #1 and #2	G. Pippin Jim Zwiener	
Polish Plate Micrometeoroid Debris Collector	W. Kinard	

List of Phase 1 Principal Investigators and Their Experiments (continued)

Phase 1B Continued

International Space Station Continued:	**U.S. Investigators**	**Russian Investigators**
Shuttle/*Mir* Alignment Stability Experiment	Russel Yates	S. Shitov, Ph.D.
Water Microbiological Monitor	Duane L. Pierson, Ph.D.	
Mir Structural Dynamics Experiment	Hyoung-Man Kim, Ph.D.	Vyacheslav Mezhin
Optical Properties Monitor	Don Wilkes	S. Naumov
		Sergey Demidov
Cosmic Radiation and Effects Activation Monitor	Peter Truscott	
Test of PCS Hardware	Rod Lofton	
Space Portable Spectroreflectometer	Ralph Carruth	Stanislov Naumov, Ph.D.
Radiation Monitoring Equipment	Mike Golightly	Vladislav Petrov
	Francis Afinidad	
Microgravity:		
Biotechnology System Facility Operations	Steve Gonda, Ph.D.	
Binary Colloidal Alloy Test	David A. Weitz, Ph.D.	
Cartilage in Space	Lisa Freed, M.D., Ph.D.	
	Steve Gonda, Ph.D.	
Biotechnology Diagnostic Experiment	Steve Gonda, Ph.D.	
Biotechnology Co-Culture	Elliot Levine, Ph.D.	
	Thomas Goodwin	
Biochemistry of 3D Tissue Engineering	Timothy Hammond, Ph.D.	
	Peter Lelkes, Ph.D.	
Candle Flame in Microgravity	Dan Deitrich	
Forced Flow Flamespread Test	Kurt Sacksteder, Ph.D.	
Opposed Flow Flamespread on Cylindrical Surfaces	Robert A. Altenkirch	
Interface Configuration Experiment	Mark Weislogel	
Liquid Metal Diffusion	Franz Rosenberger	
Mechanics of Granular Materials	Stein Sture, Ph.D.	
	Nicholas Costes, Ph.D.	
Microgravity Glovebox Facility Operations	Don Reiss, Ph.D.	
Angular Liquid Bridge Experiment	Paul Concus, Ph.D.	
Microgravity Isolation Mount Facility Operations	Bjarni Trygvasson, Ph.D.	
Queen's University Experiment in Liquid Diffusion	Reginald Smith, Ph.D.	
Passive Accelerometer System	Iwan Alexander, Ph.D.	
Protein Crystal Growth GN2 Experiment	Alexander McPherson, Ph.D.	
	Stan Koszelak, Ph.D.	
Diffusion Controlled Crystallization Apparatus	Dan Carter, Ph.D.	
Space Acceleration Measurement System	Richard DeLombard	Stanislav Ryaboukha
Technological Evaluation of Microgravity Isolation Mount (MIM)	Jeff Allen	
Colloidal Gelation	David Weitz, Ph.D.	
Canadian Protein Crystallization Experiment	Phillip Gregory	
Interferometer Protein Crystal Growth	Alexander McPherson, Ph.D.	
Space Sciences:		
Mir Sample Return	Peter Tsou, Ph.D.	
Particle Impact Experiment	Carl Maag, Ph.D.	

Attachment 11.3: Table of Phase 1 Investigations per Mission Increment

Phase 1A

Metabolic Research:	***Mir* 18/NASA 1**	**STS-71**	***Mir* 19**
Fluid and Electrolyte Homeostasis and its Regulation	X	X	
Dynamics of Calcium Metabolism and Bone Tissue	X	X	
Renal Stone Risk Assessment	X	X	
Metabolic Response to Exercise	X		
Metabolism of Red Blood Cells	X		
Red Blood Cell Mass and Survival	X		
Physiologic Alterations and Pharmacokinetic Changes During Spaceflight	X		
Humoral Immunity		X	X
Viral Reactivation	X		
Peripheral Mononuclear Cells		X	
Cardiovascular and Pulmonary Research:			
Studies on Orthostatic Tolerance With the Use of LBNP	X	X	
Studies of Mechanisms Underlying Orthostatic Intolerance Using Ambulatory Monitoring Baroflex Testing and Valsalva Maneuver	X	X X	
Maximal Aerobic Capacity Using Graded Bicycle Ergometry	X	X	
Evaluation of Thermoregulation During Spaceflight	X		
Physiological Response During Descent of Space Shuttle		X	
Neurosensory Research:			
Evaluation of Skeletal Muscle Performance and Characteristics	X	X	
Morphological, Histochemical & Ultrastructural Characteristics of Skeletal Muscle	X		X
Eye-Head Coordination During Target Acquisition	X	X	X
Posture and Locomotion	X		X
Hygiene, Sanitation, and Radiation Research:			
Microbiology	X	X	X
In-flight Radiation Measurements	X	X	X
Measurement of Cytogenetic Effects of Space Radiation	X		
Trace Chemical Contamination	X	X	X
Behavior and Performance Research:			
The Effectiveness of Manual Control During Simulation of Flight Tasks (PILOT)	X		
Fundamental Biology Research:			
Incubator	X		X
Greenhouse			X
Microgravity Research			
Space Acceleration Measurement System (SAMS)			X
Protein Crystallization Methods		X	X

Attachment 11.3: Table of Phase 1 Investigations per Mission Increment (continued)

Phase 1B

	Research Increment					
Advanced Technology:	2	3	4	5	6	7
Optizone Liquid Phase Sintering	X					X
Materials in Devices as Superconductors		X				
Commercial Protein Crystal Growth		X				
Commercial Generic Bioprocessing Apparatus		X			X	
Liquid Motion Experiment				X		
ASTROCULTURE						X
X-Ray Detector Test						X
Earth Sciences:						
Calibration & Validation of Priroda Microwave Sensors	X*	X*	X*	X*	X*	X*
Comparison of Atmospheric Chemistry Sensors on Priroda and American Satellites	X*	X*	X*	X*	X*	X*
Regional & Temperature Variability of Primary Productivity in Ocean Shelf Waters	X*	X*	X*	X*	X*	X*
Test Site Monitoring & Visual Earth Observations	X	X	X	X	X	X
Validation of Biosphere-Atmosphere Interchange Model for Northern Prairies	X*	X*	X*	X*	X*	X*
Validation of Priroda Rain Observations	X*	X*	X*	X*	X*	X*
Mir Window Documentation				X	X	

* - Priroda sensors used to support these experiments were only partially activated

	Research Increment					
Fundamental Biology:	2	3	4	5	6	7
Environmental Radiation Measurements	X	X	X	X		
Incubator-Integrated Quail Experiments on *Mir*	X					
Greenhouse - Integrated Plant Experiments		X				
Effective Dose Measurement at EVA			X	X		
Cellular Mechanisms of Spaceflight Specific to Plants			X			
Standard Interface Glovebox			X			
Developmental Analysis of Seeds Grown on *Mir*				X		
Effects of Gravity on Insect Circadian Rhythmicity				X		
Active Dosimetry of Charged Particles					X	
Human Life Sciences:						
Effects of Spaceflight on Gaze Control	X					
Anticipatory Postural Activity	X					
Evaluation of Skeletal Muscle Performance & Characteristics		X				
Effects of Long-Duration Spaceflight on Eye, Head, & Trunk Coordination During Locomotion	X	X				
Assessment of Humoral Immune Function	X	X	X		X	X
Bone Mineral Loss & Recovery	X	X	X	X	X	X
Collecting *Mir* Source & Reclaimed Waters	X	X	X*	X*	X*	X*
Analysis of Volatile Organic Compounds on *Mir*	X	X	X*	X*	X*	X*
Microbiological Investigations of the *Mir* Crew		X	X*	X*	X*	X*
Gas Analyzer System Metabolic Analysis Physiology	X	X	X	X		
Magnetic Resonance Imaging After Exposure to Microgravity	X	X	X	X	X	X
Protein Metabolism	X	X				
Renal Stone Risk Assessment	X	X			X	X
Crew Member & Crew-Ground Interactions		X	X	X	X	X

Attachment 11.3: Table of Phase 1 Investigations per Mission Increment (continued)

Phase 1B Continued

	Research Increment					
Human Life Sciences Continued:	2	3	4	5	6	7
Sleep Investigations			X	X	X	
Frames of Reference for Sensorimotor Transformations			X	X		
Cardiovascular Investigations					X	X
* - performed under the Space Medicine Program (SMP)						
International Space Station Risk Mitigation:						
Mir Audible Noise Measurement	X					
Shuttle/*Mir* Alignment Stability Experiment	X	X				
Enhanced Dynamic Load Sensors on *Mir*	X		X		X	
Mir Electric Field Characterization	X	X	X			
Orbital Debris Collector	X	X	X	X	X	
Passive Optical Sample Assembly #1 and #2	X	X	X	X	X	
Polish Plate Micrometeoroid Debris Collector	X	X	X	X	X	
Water Microbiological Monitor		X	X	X*	X*	
Mir Structural Dynamics Experiment		X	X	X	X	
Optical Properties Monitor			X	X	X	
Cosmic Radiation and Effects Activation Monitor					X	X
Test of PCS Hardware					X	X
Space Portable Spectroreflectometer					X	
Radiation Monitoring Equipment					X	X
* - performed under the SMP						
Microgravity:						
Interface Configuration Experiment	X					
Candle Flame in Microgravity	X					
Forced Flow Flamespread Test	X					
Angular Liquid Bridge			X			
Opposed Flow Flamespread on Cylindrical Surfaces			X			
Binary Colloidal Alloy Test		X			X	
Passive Accelerometer System		X				
Biotechnology System Facility Operations	X	X	X	X	X	X
Biotechnology Diagnostic Experiment			X	X	X	
Cartilage in Space		X				
Biochemistry of 3D Tissue Engineering					X	
Biotechnology CoCulture						X
Mechanics of Granular Materials	X				X	
Microgravity Glovebox Facility Operations	X	X	X	X	X	
Microgravity Isolation Mount Facility Operations	X		X		X	X
Technological Evaluation of MIM	X					
Liquid Metal Diffusion			X			
Queen's University Experiment in Liquid Diffusion			X		X	X
Protein Crystal Growth GN2 Experiment	X	X	X	X		X
Diffusion Controlled Crystallization Apparatus	X	X	X	X		X
Space Acceleration Measurement System	X	X	X	X	X	X
Colloidal Gelation				X		
Canadian Protein Crystallization Experiment					X	
Interferometer Protein Crystal Growth					X	

Attachment 11.3: Table of Phase 1 Investigations per Mission Increment (continued)

Phase 1B Continued

	Research Increment					
Space Sciences:	2	3	4	5	6	7
Mir Sample Return Experiment	X	X	X			
Particle Impact Experiment	X	X	X			

Attachment 11.4: Phase 1 Postflight Reports

PHASE 1A

PUBLISHED MARCH 1998

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2.1.1 Fluid and Electrolyte Homeostasis, Dynamics of Calcium Metabolism and Bone Tissue, Red Blood Cell Mass and Survival (*Mir* 18 Final Science Report) 1-3

2.1.3 Renal Stone Risk Assessment During Long-Duration Spaceflight (*Mir* 18 Final Science Report) 1-9

2.2.3 Metabolic Response to Exercise (*Mir* 18 Final Science Report) 1-19

2.3.1 Physiologic Alterations and Pharmacokinetic Changes During Spaceflight (*Mir* 18 Final Science Report) 1-25

2.4.2 Assessment of Humoral Immune Function During Long-Duration Spaceflight (STS-71 Final Science Report) 1-35

2.4.3 Reactivation of Latent Viral Infections in the *Mir* Crew (*Mir* 18 Final Science Report) 1-41

2.4.3 Reactivation of Latent Viral Infections in the *Mir* Crew (*Mir* 19 Final Science Report) 1-49

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3.2.2 Evaluation of Thermoregulation During Long-Duration Spaceflight (*Mir* 18 Final Science Report) 2-31

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4.1.2 Morphological, Histochemical, and Ultrastructural Characteristics of Skeletal Muscle (*Mir* 18 Final Science Report) 3-13

4.2.1 Eye-Head Coordination During Target Acquisition (*Mir* 18/19 Final Science Report) 3-25

4.2.4 Biomechanics of Movement During Locomotion (*Mir* 18 Final Science Report) 3-53

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4.2.4 Alterations in Postural Equilibrium Control Associated With Long-Duration Spaceflight (*Mir* 18 Final Science Report) 3-79

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5.3 Trace Chemical Contamination: Water Quality (*Mir* 19 Final Science Report) 4-167

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6.2.2 The Effectiveness of Manual Control During Simulation of Flight Tasks (Pilot) (*Mir* 18 Final Science Report) 5-3

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Exercise	Evaluation of Skeletal Muscle Performance and Characteristics (NASA 3 Operational Accomplishment Report)	4-67
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DCAM	Ambient Diffusion Controlled Protein Crystal Growth (NASA 3 Operational Accomplishment Report)	5-5
BCAT	Binary Colloidal Alloy Tests (NASA 3 Operational Accomplishment Report)	5-7
CFM	Candle Flame in Microgravity (NASA 2 Operational Accomplishment Report)	5-9
Cartilage	Cartilage in Space (NASA 3 Operational Accomplishment Report)	5-11
FFFT	Forced Flow Flame Spreading Test (NASA 2 Operational Accomplishment Report)	5-13
ICE	Interface Configuration Experiment for the *Mir* Glovebox (NASA 2 Operational Accomplishment Report)	5-15
MGM	Mechanics of Granular Materials (STS-79 Operational Accomplishment Report)	5-17
Glovebox	Microgravity Glovebox Facility (MGBX) (NASA 2 Operational Accomplishment Report)	5-21
Glovebox	Microgravity Glovebox Facility (MGBX) (NASA 3 Operational Accomplishment Report)	5-23
MIM	Microgravity Isolation Mount (NASA 2 Operational Accomplishment Report)	5-25
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PCG-Dewar	Protein Crystal Growth (PCG) GN$_2$ Dewar Experiment (NASA 3 Operational Accomplishment Report)	5-29
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PUBLISHED AUGUST 1997

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Attachment 11.5: List of Phase 1 Peer-Reviewed Publications

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Attachment 11.5: List of Phase 1 Peer-Reviewed Publications (Continued)

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Yang, T. C., George, K., Johnson, A. S., Durante, M., Fedorenko, B. S. "Biodosemitry results from Space Flight *Mir*-18." *Radiation Research*, 148 (5 Suppl): S17-S23, (1997).

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12.1 Responsibilities

The NASA/Russian Public Affairs Working Group (WG-1) was responsible for the planning, development, and execution of all public affairs aspects of the Phase 1 Shuttle/*Mir* program. This included the issuing of press releases, status reports and press kits, the scheduling and conduct of press conferences, distribution of television, coordination and execution of interviews by media and educational organizations with crew members on both the Shuttle and the *Mir* Space Station, distribution of photographs, guest operations, and selection and logistical coordination of commemorative items. In addition, international television and video crews were granted access to document astronaut and cosmonaut training, space hardware and mission control operations in both the U.S. and Russia.

12.2 Structure

The WG-1 was led by U.S. and Russian co-chairs and met for the first time at the Russian (MCC-M), Korolev, Russia, in June 1994. Public Affairs representatives from NASA Headquarters, NASA's Johnson Space Center (JSC), MCC-M, Russian Space Agency, Y.A. Gagarin Cosmonaut Training Center, RSC Energia (RSC-E), Space Command, Institute of Biomedical Problems (IBMP) and Central Scientific and Research Institute for Machine Engineering participated in this WG.

It was decided during the first WG-1 meeting to establish three sub-working groups: television, news operations, and protocol and guest operations. These sub-working groups were responsible for the detailed planning in these areas. We found this to be a very useful organizational structure and it is being used in the International Space Station (ISS) Partners Public Affairs Working Group.

A NASA/Russian Public Affairs Plan was developed and signed prior to U.S. Astronaut Norm Thagard's flight onboard a Soyuz capsule to the Russian *Mir* space station as well as for each Shuttle/*Mir* docking mission. This plan outlined the exchange of information, photographs, video, biographies, preflight and mission press conferences, exchange of in-flight television, in-flight interviews, written status reports, protocol activities, guest operations, receptions, commemorative items, and a contingency plan.

Over the years, the WG-1 participants developed a strong working relationship that was based on mutual respect and trust. As the relationship matured, it became easier to plan and coordinate public affairs activities.

NASA placed Public Affairs representatives on a rotating basis at MCC-M for Astronaut Norm Thagard's 105-day mission onboard the *Mir* Space Station (March 16-June 29, 1995). Once Shannon Lucid was launched on board the Space Shuttle

(STS-76) on March 22, 1996, NASA public affairs officers began a continuous presence in MCC-M and in June 1997, a permanent Public Affairs Officer (PAO) was located at MCC-M through the end of the Phase 1 program.

12.3 Accomplishments

The value of having a PAO at MCC-M was clearly evident in 1997, when the world's news media paid increased attention to the *Mir* due to a solid oxygen generation canister fire and the Progress collision. The NASA PAO worked closely with the NASA Operations Lead, Russian Public Affairs representatives, and Public Affairs officials at NASA Headquarters and JSC to coordinate the timely release of accurate information to the news media. This was a challenge for both sides, particularly with a substantial time difference between Moscow and the U.S.

NASA and MCC-M management held news media briefings on an almost daily basis after the Progress accident. In addition, NASA released daily written status reports for weeks following the collision.

NASA and the MCC-M Public Affairs representatives consulted frequently and exchanged information about *Mir*-related public affairs activities in the U.S. and Russia. They also coordinated the visits of U.S. news media representatives to MCC-M and other Russian organizations, and finalized the weekly in-flight PAO events with U.S. astronauts onboard *Mir*.

The story of the Phase 1 Shuttle-*Mir* program was perhaps best illustrated through the exchange of television between the U.S. and Russia and the broadcast of all key events to the world through NASA Television. Through the eyes of television cameras on the *Mir*, U.S. media and audiences throughout the world were able to see a variety of crew activities on board the Russian station and witnessed key operational accomplishments such as Shuttle, Progress and scientific module dockings with *Mir* as well as space walk activity, including the first joint U.S.-Russian space walk conducted in April 1997.

Similarly, through Shuttle television systems, all elements of the *Mir* and crew activities were seen by viewers around the world, highlighting the collaborative work undertaken during the joint cooperative program. One of the most effective video segments captured during the Shuttle-*Mir* docking missions was a tour of the *Mir*'s modules, conducted both on STS-79 and STS-84. In-flight interviews and news conferences held with U.S. astronauts residing on the *Mir* and the cosmonauts were broadcast in the U.S. and distributed worldwide. WG-1 worked extensively to arrange VIP calls to the joint crews during docked operations and coordinated events such as the celebration of the 50th U.N. Anniversary during the STS-74 mission in November 1995. One of the most important images produced from the Shuttle-*Mir* program was taken from a Soyuz vehicle of Atlantis joined to the *Mir* during the first docked mission on STS-71 in July 1995.

The WG-1 designed and produced commemorative items. These items included plaques for each mission that were flown to *Mir* on board the Space Shuttle and Phase 1 aluminum coins that contained metal from both the Space Shuttle and the *Mir*. U.S. and Russian flags and mission patches were flown on the Shuttle to *Mir* which were returned for use as presentation items. When other international crew members flew, flags from their countries were also flown.

As the result of the Space Shuttle/*Mir* docking program, people all around the world became very familiar with the Russian *Mir* space station. Our WG was very successful in providing information to the general public through the release of our joint products and joint efforts.

12.4 Lessons Learned and Applications to ISS

On occasion during Phase 1, in particular during the fire and the aftermath of the Progress collision, NASA had to release information to the public about developments on the *Mir* many hours after Russian officials released information to reporters in MCC-M. While it is important to wait for the proper officials to address the contingency issues, information should be provided to the news media as quickly and accurately as possible. During ISS, we will have to issue news releases in a timely manner and direct comments to the news media with consistent information. The release of that information should contain initial information to the public followed by more detailed information through technical experts as soon as updated information is acquired.

The importance of having a NASA public affairs presence in MCC-M was demonstrated during Phase 1. We now have two PAOs permanently assigned to MCC-M and will continue to have that presence throughout the ISS program. In addition, NASA has invited all the international partners to have a permanent public affairs representative based at the JSC news room to coordinate ISS public affairs activities.

On occasion, operational issues resulted in the last minute cancellation of scheduled U.S. television events from *Mir*. The success of the missions and the safety of the crew on ISS will always take priority. But, we will make every effort to try to accommodate scheduled television events from the Russian ISS segment during Expedition I. For the duration of Expedition 1, the Russian television system link will be the only broadcast quality television path available to us from ISS.

We are in the process of developing an ISS public affairs contingency plan that will be approved by the ISS program management and international partners prior to the launch of the first ISS component, the "Zarya" or FGB module.

To create a more efficient working environment in MCC-M during ISS operations, the news media should have a special room in which they can conduct their business away from the areas where technical experts are working, including the MCC-M balcony and the flight control room. The news media will have access to Public Affairs representatives and technical experts for interviews in a separate office in MCC-M similar to the way the news media conducts its interviews at JSC.

NASA 2 astronaut S. Lucid and NASA 3 astronaut J. Blaha aboard *Mir*

Section 13 - Applications to the International Space Station (ISS)

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13.1 Unique Issues

The developers of the ISS program face many issues that are unique in world practice.

An analysis of the results of *Mir*-Shuttle and *Mir*-NASA program implementation showed that a significant number of these issues have already been resolved and could be successfully be used in the ISS program.

Together, the experience acquired in fulfilling the joint Russian-American program and which can be adapted for ISS operations, is presented in eleven separate blocks in Figure 13.1.

Each block represents activities in several areas with each area having several dozen or even hundreds of separate resolved issues. Thus even today, as practical missions are carried out for the *Mir*-NASA program, several thousand issues regarding the interaction between the ISS Russian and American segments have been worked out.

13.2 Use of Shuttle for the Space Station Logistics Support

The **first block** examines utilization of the Shuttle for transport and engineering support of the orbital station. This is the most significant achievement.

Before making flights to the *Mir* station, the Shuttle carried out solitary flights as a carrier of satellites and scientific labs with no active dockings or payload deliveries to a station.

In nine Shuttle flights to *Mir*, several docking alternatives were developed. The Shuttle docked with the station in three of its configurations: to the axial and lateral nodes of the Kristall module and to the docking compartment, which was mated to the Kristall module.

The Shuttle itself had two configurations: docking using its docking module (DM) and the special Russian docking compartment, which remained on the station after the docking. The Shuttle docked along the velocity vector and to the nadir and performed a fly-around of *Mir*. During STS-91, the Shuttle was in a configuration characteristic of the ISS.

The experience gained from various dockings will be applied to the first stage of ISS assembly.

As a delivery vehicle for various payloads sent to *Mir*, the Shuttle became a peer of the Progress-M spacecraft. Over the course of nine missions, it has delivered 22.9 metric tons of payloads, including large DMs, to the *Mir* station.

EXPERIENCE IN COOPERATION FROM JOINT RUSSIAN - U.S. PROGRAM *MIR*-NASA APPLICABLE TO ISS

Figure 13.1

1. Shuttle use for the space station logistics support

- developed Shuttle-to-*Mir* docking operation
- gained experience in delivery of large-sized modules and logistic cargo to *Mir*
- returned cargo from space station in each mission
- verified the use of Shuttle for U.S./Russian crew rotation
- proved efficiency of use of reusable vehicles of Shuttle and Buran type

2. Interaction between international crews

- verified long-term international missions, including psychological support
- verified operations for hardware
- installation/dismantling, equipment transfer from Shuttle to *Mir* and back
- gained experience in joint science
- experience of crew medical support has been gained
- verified interaction in EVAs
- international crew training experience gained
- gained experience in increment of tasks during the flight

3. Space station systems serviceability over a long-term mission

- thermal control system, including hydraulic lines of heat-transport medium
- on-board cabling
- main propulsion unit
- pressurized hull
- power supply system

4. Experience in off-nominal situations recovery

- fire in Kvant module
- leakage in thermal control system loops
- life support system repairs
- Spektr module depressurization
- repair of the onboard computer system

5. Joint ground operations with logistic items

- development joint upmass and downmass process flow
- verified complex cargo assembly and preflight testing
- gained joint experience in simulating cargo accommodation
- performed large amount of acceptance tests of U.S. scientific equipment

6. Research of Station Environment

7. Russian/U.S. cargo integration

- food supplies, water
- crew life support equipment (water containers, CO_2 cartridges, PHA, clothing, Braslet, Electron-B, etc.)
- crew safety support equipment (IELK)
- equipment for *Mir* operation (gyrodyne, batteries, current converter ПЕФБ-1 etc.)
- medical kits
- tools and repair equipment
- gases O_2, N_2

8. Development of joint documents

9. Gained experience in joint Shuttle/*Mir* complex control from MCC-H/MCC-M

10. Science Research Accomplishments

11. Experience in combining two space engineering schools, both of which were developing independently before

Among the cargo are the following: Russian: gyroscopes, an Elektron, storage batteries, life-support system hardware, water for the crew, and more than 200 types of American science equipment.

However, the Shuttle did not just deliver cargo to *Mir*. It also returned the results of experiments, scientific devices, and *Mir* station hardware for analysis and reuse: gyrodynes, an Elektron, remote-operator control mode equipment and Kurs hardware, storage batteries, and much else. Over the course of nine flights, the Shuttle vehicles returned 7.8 metric tons of cargo. The total mass of the cargo traffic was 30.7 metric tons.

The experience gained from delivery and the return of Russian cargo will be virtually completely incorporated in Phase 2, since the ISS Russian segment systems are in many ways identical to those installed on *Mir*. It will also be expedient to apply experience acquired from the delivery and return of American science equipment to the ISS.

During the flights, various alternatives for delivering and returning crews were developed. The crew consisting of Dezhurov, Strekalov, and Thagard was launched in the Soyuz-TM and returned on the Shuttle, while Solovyev and Budarin took off on the Shuttle and returned in the Soyuz-TM.

American astronauts Shannon Lucid, John Blaha, Jerry Linenger, Michael Foale, Dave Wolf, and Andrew Thomas were launched and returned on the Shuttle. All of these methods will be implemented for the ISS. The first ISS crew will launch in the Soyuz-TM and will return on the Shuttle.

On the whole, fulfillment of transport operations by the Shuttle has proven the effectiveness of utilizing reusable vehicles for supplying orbital stations.

13.3 Interaction Between International Crews

The **second block** reflects experience acquired in the sphere of cooperation between international crews. The American astronauts spent a total of 942 days on *Mir*, thus exceeding the total presence of all foreign astronauts on the Salyut and *Mir* stations. The successful experiences of American astronauts in long-duration flights on *Mir* of from 115 to 188 days and their flights with two Russian crews that replaced one another are of great importance in ISS program planning. Practice has shown that it is not necessary to limit the length of missions to three months or to launch and return with the same crew. This was confirmed when A. Solovyev and M. Foale, who were launched aboard different spacecraft, performed an extravehicular activity (EVA) on 6 September 1997.

Loading and unloading the Shuttle in orbit is one of the most important and labor-intensive operations. There were doubts at the start of the program as to whether the *Mir* and Shuttle crews would have enough time to perform these operations during a short five-docked day mission. Today these operations have been successfully developed. Russian cosmonauts and American astronauts work smoothly and very quickly. During STS-86, the total mass of cargo transferred from the Shuttle to *Mir* and vice versa was 4525 kg.

The *Mir* and Shuttle crews have acquired experience in simultaneously conducting two science programs based on joint experiments, which will undoubtedly be important for the ISS.

One feature of the American science program is the large quantity of science equipment that is replaced during each Shuttle flight (on average, 600 kg), which is anticipated for the ISS.

Joint EVA experience should be mentioned. Linenger, Foale, and Wolf egressed in Russian space suits, and Titov worked in an American space suit during STS-86. During EVAs, cosmonauts worked with American payloads, while astronauts worked with Russian ones during STS-86. The astronauts on the station accompanied the cosmonauts during EVAs, and helped them with operations.

Other accomplishments were training astronauts and cosmonauts in each other's language, methodologies, development of tools to facilitate technical operations in orbit, and the creation of efficiencies in mission training. Training of astronauts and cosmonauts conducted at each other's space centers broadened the scope of training techniques, styles and methods. Experience was gained in astronaut training as cosmonaut researcher and onboard engineer-2 for individual systems during *Mir* long-duration missions.

13.4 Space Station System Serviceability Over a Long-Term Mission

The **third block** is very important because the experience acquired in long-duration station system support in space is unique. The *Mir* station is in its 13th year of flight, and several problems, such as the biocorrosion of the thermal control system, became apparent only in the 12th year of operation. The experience gained has made it possible to adopt measures to ensure 15 years of flight and 10 years of operation of such basic systems and ISS module assemblies as the thermal control system, the onboard cable network, the integrated propulsion system, the pressure hull, pumps, valves, and equipment for controlling the pencil-beam antenna. Considering the fact that this experience was gained during the actual flight of the orbital station, it is invaluable.

A joint understanding was developed on how noncritical systems can be operated until they fail, then can be replaced through routine maintenance without compromising safety or mission success. In addition a joint understanding was developed that multiple oxygen-generating systems are essential to ensure uninterrupted operations while maximizing safety margins.

13.5 Experience in Off-Nominal Situations Recovery

In the **fourth block**, all of the emergency situations that are listed occurred on *Mir* and were successfully eliminated by the crews with the participation of American astronauts.

Of course, the emergency situations on *Mir* were not specially planned; nevertheless, the experience in resolving the situations is doubtless a contribution to the ISS program.

It is especially important to mention preparations for repressurizing the Spektr module. So far, only plans for such operations have been drawn up for the ISS. They have become necessary for the *Mir* station. Working under the shortest of deadlines, RSC-Energia (RSC-E) and the Khrunichev Space Center developed repair hardware for sealing possible leaks in space. The hardware has been tested, was sent to Kennedy Space Center (KSC), and was delivered to *Mir* during STS-86 in September 1997.

Unfortunately, despite the repair operations which were conducted, including crew EVAs, up to now it has not been possible to repressurize the Spektr module. However, the results obtained during full-scale testing may in fact be included in the scope of work performed for the ISS.

13.6 Joint Ground Operations With Logistics Items

The **fifth block** notes categories of joint work during ground preparation of payloads.

Presently, virtually all ground service operations necessary for transport of Russian payloads on the Shuttle and American payloads on *Mir* modules and Progress and Soyuz vehicles have been developed and fine-tuned with consideration of the specific requirements of equipping the orbital station.

This allows American and Russian experts, in particular, to quickly resolve issues concerning delivery of emergency payloads. Thus, in April 1997, a month before the launch of STS-84, a 140-kg Elektron unit was stowed in the Spacehab module. In August of that same year, and a month before the launch of STS-86, 300 kg of repair equipment for the Spektr module was placed in the Spacehab and on the mid-deck. Experience in real-time stowage of payloads on delivery vehicles for the orbital station will certainly be incorporated into Phase 2.

Preparation operations and preflight testing of integrated payloads have been developed. The Russian Spektr and Priroda modules and Progress-M spacecraft have delivered 2000 kg of American science equipment which has been tested at different places, including the Baikonur launch site. At the same time, a Russian DM and solar array units were prepared and placed in the Shuttle payload bay (STS-74) at KSC.

Acquired experience in joint preflight testing of integrated payloads, in particular the DM, will be applied to the ISS program when the Russian science power platform and its solar arrays are prepared for transport on the Shuttle.

All means of information exchange, including joint mockups, are widely used for payload stowage operations.

It is important to note the concurred work of American and Russian experts in flight safety assurance for the Shuttle when carrying Russian payloads and when docked with *Mir*, including during execution of the American science program.

Acceptance test procedures for the primarily American science equipment, including the issuance of safety certificates, have been adjusted.

All of these inconspicuous operation categories will be a characteristic part of the ISS program, and less time will be required to adjust them.

13.7 Research of Station Environment

The **sixth block** comprises activities on station environment studies including *Mir*-Shuttle stack attitude control. A rack for isolating sensitive scientific experiments from disturbing vibrations caused by normal crew activity was successfully tested on *Mir*. Data was collected on effect of long-duration exposure of hardware to space environment through the *Mir* Environmental Effects Payload, which was deployed and retrieved by astronauts and cosmonauts on joint space walks.

For the first time experience was gained in attitude control of a big and flexible structure *Mir* + Shuttle. Attitude control was supported by both reaction control jets (*Mir* and Shuttle) and gyrodynes. Particularly, the procedure of using jets of the Progress vehicle for desaturation of gyrodynes will be used during attitude control of ISS for desaturation of both Russian gyrodynes and American control moment gyrodynes.

13.8 Russian/U.S. Cargo Integration

The **seventh block** concerns issues regarding integration of Russian and American payloads. This integration falls under two categories:

- developing and utilizing American equipment and life-support systems delivered to *Mir*;
- constantly expanding the list of partners' payloads in national transport vehicles.

Today, *Mir* uses American life-support systems as well as traditional Russian equipment and life-support systems.

Here is a partial list:

- the Kvant module has a Russian solar array deployed on one side and an American solar array deployed on the other,
- 50% of foodstuffs have been American while the other 50% have been Russian,
- both American and Russian CO2 absorbers, water storage tanks, medical kits, instruments, and water have been used,
- after the Shuttle is docked, its air is exchanged with the air of the *Mir* station.

Of particular note as a contribution to Phase 2 is the resolved problem of using a Shuttle power-supply system byproduct, water, on the orbital station. On the one hand, it was not necessary to load the Shuttle with water because water accumulated by the end of the flight, but on the other, this water could not be stored for long on the station, which is necessary for a long-duration flight.

Thus, throughout these flights, Russian and American experts worked in turn to resolve this issue, and now, the ISS crew will be able to consume water delivered during each Shuttle flight with no problems.

13.9 Development of Joint Documents

The **eighth block** notes that joint documents were issued for the *Mir*-NASA program.

There are fairly many such joint documents. More than fifteen were issued on operations alone for each flight.

Documents such as the Russian cargo manifest and interface control documents are wholly transferable to Phase 2.

Experience in creating joint Russian-American documents is already widely used in the development of ISS documentation, and this has accelerated the work process.

13.10 Experience Gained in Joint Shuttle/*Mir* Complex Control From MCC-H/MCC-M (Mission Control Centers in Houston and Korolev)

The **ninth block** is concerned with the large experience gained by both sides in the joint control process of the *Mir* and Shuttle during nine short- and seven long-duration missions.

Shuttle and *Mir* were originally developed independently of each other and there was no compatibility between the two. MCC-M and MCC-H also operated under individual programs independently of each other.

The potential experience in MCC joint operations was only available from the short-duration Apollo Soyuz Program, completed in 1975. This experience was fully utilized, but it was insufficient.

The Phase 1 tasks were of two types:

- conduct scientific experiments;
- gain operational experience for use in Phase 2.

Many engineering as well as operational decisions were required in order to ensure the capability of *Mir* and Shuttle and joint control of the mated vehicles from two MCCs, separated from each other by thousands of miles, in different time zones, each with their own traditions and languages. Flight control took place under changing *Mir* configurations and constantly developing tasks. In this way, it was like simulating the process of ISS development on orbit.

All Phase 1 tasks were successfully completed, which serves as proof of the technical capabilities of both sides.

As a result it is possible to ascertain that during the course of Phase 1 a foundation was created for successful Phase 2 preparations, and the technological structure and methodology of joint flight control for future international programs such as the ISS were created and refined.

We can note acquired experience in the following areas:

- study of flight control experience of Russian and U.S. vehicles;
- structure of the joint vehicle control groups of different countries;
- structure of the joint ground and flight data files for flight control and crew operations;
- the set of technical operations for joint flight planning of vehicles from both countries;
- the set of procedures for jointly making decisions for both nominal flight and in emergency situations;
- mutual use of capabilities of the partners' flight and ground segments;
- communications system and data exchange for flight control between MCC-M and MCC-H;
- organizing international crew operations and the interaction of the MCCs with the crews;
- simultaneous execution of two or more science programs from different countries;
- procedures for publicizing information about flight activities;
- integration of *Mir* and Shuttle onboard systems.

In addition, the joint flight of the two 100-ton vehicles—the Shuttle and the *Mir* station in mated flight—in many ways simulated the flight of the American and Russian ISS segments, since the complex has many distinctive characteristics of the international station: the docked Shuttle, a large crew, two science programs and joint experiments, transfer and stowage of cargo and so on, that also applies to Phase 2.

13.11 Science Research Accomplishments

The **tenth block** represents the many important scientific accomplishments of the Phase 1 Program. These accomplishments are summarized well in section 11 of the report under the subheading "WG-4 Accomplishments."

13.12 Combining Experience of Two Space Engineering Schools

The **eleventh block** describes how, on the whole, two technical schools of space engineering were successfully integrated during implementation of the *Mir*-Shuttle and *Mir*-NASA programs. Furthermore, issues of separate work locations, different technical and spoken languages, and production of identical documentation were resolved.

Resolving the issues listed above required the diligent work of hundreds of Russian and American specialists. Their efforts made the program highly productive.

***Atlantis* docked to *Mir* during STS71**

The Shuttle *Endeavor* lands at KSC after STS-89

Section 14 - Conclusions

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Conclusions

The Phase 1 Program endured through a fire, a collision, several power shortages, and other significant contingencies and last-minute adjustments and proudly accomplished its four main objectives:

1. Learn how to work with international partners.
2. Reduce risks associated with developing and assembling a space station.
3. Gain operational experience for NASA on long-duration missions.
4. Conduct life science, microgravity, and environmental research programs.

U.S. and Russian space programs bridged cultural, linguistic, and technical differences and created a joint process for analysis, mission safety assessment, and certification of flight readiness. This collaboration resulted in a joint program spanning more than four years that capitalized on a combined four decades of spacefaring expertise both in Earth orbital and inter-cosmos exploration to build the foundation for an International Space Station.

Section 15 - Acronym List

A/G	Air to Ground
ACT	a Russian certification statement
AD	Accompanying Documentation
ADV	Advanced Technology
AIT	Analysis and Integration Team
ALIS	Analysis of Critical Liquids in Space
AMERD	Astronaut Medical Evaluation Requirements Document
APAS	Androgynous Peripheral Assembly System
APDA	Androgynous Peripheral Docking Assembly
APU	Air Pressurization Unit
AT	Acceptance Test
BCAT	Binary Colloid Alloy Test
BDC	Baseline Data Collection
BNA	Boeing North American
BPA	Nitrogen Purge Unit
BTS	Biotechnology System
BVK	Vacuum Valve Unit
CC	Crew Commander
CCB	Configuration Control Board
cfm	cubic feet per minute
CFM	Candle Flame in Microgravity
CHAPAT	Active Dosimetry of Charged Particles
CNES	French Space Agency
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COFR	Certificate of Flight Readiness
COSS	Crew On-Orbit Support Systems
CR	Cosmonaut Researcher
CWC	Contingency Water Container
DARA	German Space Agency
DCAM	Dialysis Crystallization Apparatus for Microgravity
DFRC	Dryden Flight Research Center
DID	Dimensional Installation Drawings
DM	Docking Module

DMT	Decreed Moscow Time
DOR	Director of Operation, Russia
EDA	External Dosimeter Array
EDLS	Enhanced Dynamic Load Sensors
EDV	Storage Tank
EID	Electrical Interface Drawing
EMU	Extravehicular Mobility Unit
ES	Earth Sciences
ESA	European Space Agency
ESC	Electronic Still Camera
EVA	Extravehicular Activity
FB	Fundamental Biology
FE	Flight Engineer
FEPC	Flight Equipment Processing Contract
FES	Flash Evaporator System
FFFT	Forced Flow Flame Spreading Test
FS	Flight Surgeon
GBx	Glove Box
GCTC	Gagarin Cosmonaut Training Center
GN	Gaseous Nitrogen
HLS	Human Life Sciences
HMST	Hazardous Material Summary Table
IBMP	Institute for Biomedical Problems
ICD	Interface Control Document
ICE	Interface Configuration Experiment
IELK	Individual Equipment and Liner Kit
IPRD	Integrated Payload Requirements Document
IPT	Integrated Product Team
IRMIS	Iodine Removal and Mineral Injection System
ISS	International Space Station
ISSP	International Space Station Program
IVA	Intravehicular Activity
JSAWG	Joint Safety Assurance Working Group
JSC	Johnson Space Center
KSC	Kennedy Space Center
lb	pounds
LDM	Long Duration Mission
LiOH	Lithium Hydroxide

LPS	Liquid Phase Sintering
MCC	Mission Control Center
MCC-H	Mission Control Center - Houston
MCC-M	Mission Control Center - Moscow
MEEP	*Mir* Environmental Effects Payload
MG	Microgravity
MGBx	Microgravity Glove Box
MIM	Microgravity Isolation Mount
MIPS-2	*Mir* Interface Payload System
MiSDE	*Mir* Structural Dynamics Experiment
mmHg	millimeters of Mercury
MMO	Mission Management Office
MOD	Mission Operations Directorate
MOIWG	Mission Operations Integration Working Group
MOST	*Mir* Operations Support Team
MS	Mission Specialist
MSDS	Material Safety Data Sheets
MSMK	*Mir* Supplemental Medical Kit
MSRD	Mission Science Requirements Document
MSRE	*Mir* Sample Return Equipment
MSWG	Mission Science Working Group
MT3	Flight Integration Office at JSC
MVAK	Module Vertical Access Kit
N2	Nitrogen
NASA	National Aeronautics and Space Administration
nms	newton - meter - seconds
NSTS	National Space Transportation System
O_2	Oxygen
ODS	Orbiter Docking System
OMS	Orbital Maneuvering Subsystem
ONS	Off-Nominal Situation
OPM	Optical Properties Monitor
OS	Orbital Station
OV	Orbiter Vehicle
P1RD	Phase 1 Requirements Document
PDRS	Payload Deployment and Retrieval System
PED	Payload Experiment Developers

PGOC	Payload Ground Operations Contractor
PI	Principle Investigator
PIE	Particle Impact Experiment
PIPS	Payload Integration Planning System
PL	Payload
POSA	Payload Operations Support Area
PRCS	Primary Reaction Control System
PS	passport
psia	pounds per square inch absolute
PSRP	Payload Safety Review Panel
PUP	Payload Utility Panel
PWQ	Process Waste Questionnaire
QUELD II	Queen's University Experiment in Liquid Diffusion
RCS	Reaction Control System
RNDZ/PROX/OPS	Rendezvous/Proximity Operations
RIO	Russia Interface Officer
RMS	Remote Manipulator System
RR	Replan Request
RSA	Russian Space Agency
RSC-E	Rocket Space Corporation - Energia
SAFER	Simplified Aid for EVA Rescue
SAMS	Space Acceleration Measurement System
SAR	Safety Analysis Report
SCAT	Spaceflight Cognitive Test
SIWG	Systems Integration Working Group
SMP	Space Medicine Program
SOIFW	Shuttle Orbiter In-Flight Food Warmer
SPPF	Spacehab Payload Processing Facility
SPSR	Space Portable Spectral Reflectometer
SS	Space Sciences
SSPF	Space Station Processing Facility
STS	Space Transportation System
SVS	Space Vision System
SWC	Solid Waste Container
TCS	Trajectory Control Sensor
TEF	Thermoelectric Freezer
TEHOF	Thermoelectric Holding Facility
TEM	Technological Evaluation of the MIM

TEPC	Tissue-equivalent Proportional Counter
TLD	Thermo Luminescence Dosimeter
TORU	Teleoperator mode
TsUP	Mission Control Center-Kaliningrad (MCC-M)
TV	Television
USA	United States of America
VB-3	Onboard Exercise Training Equipment
VHF	Very High Frequency
WETF	Weightless Environment Training Facility
WG	Working Group
БКВ-3	Air Conditioning Unit
БМП	Contaminants Filtering Unit
БО	Habitation Module
БОВа	On-board Air Dehumidifier, Autonomous
ГМО	Medical Support Group
ДОН-17КС	*Mir* Core Module Integrated Simulator
ДСБ-4	Auxiliary Solar Array
ИЛ76-МДК	EVA Training Aircraft designation
КАВ	Atmospheric Moisture Condensate
КМ	Matrix Switching Unit
КМУ	Simulator Facility Complex
КСОЖ	Life Support Systems Complex
КСП	Command Signal Panel
МБП	Biomedical Training
НГО	Unpressurized Compartment
НИИППиСПТ	Scientific Research Institute for Food Preparation and Specialty Food Technology
НИиЭ	Scientific Investigations and Experiments
НХР	Exterior Cold Radiator Panel
ОДУ	Integrated (combined) Propulsion System
ОНИКС	Krater V Control Unit
ПГО-1	Instrument/Cargo Compartment
ПДС	Permanently Operating Systems
ПЗ-1	Latch Drive
ПНО	Instrumentation/Scientific Compartment of Kvant-2.
ПСИ	Acceptance Test
ПРП	Russian acronym for Deputy Flight Director (PRP)

РПВ-2, 3В	Hand-operated Rotary Valve
СА	Descent Module
СА-БО	Hatch between Descent Module and Habitation Module
СБ-2 (- 4)	Solar Array (designation 2, 4)
СВУ-3	Scuba Gear designation
СОА	Vozdukh Atmospheric Purification Systems
СОЖ	Life Support System
СОТР	Thermal Mode Control System
СП-ЭО	Descent - Long Duration Crew
СУБК	Onboard Complex Control System
СУД	Motion Control System
ТДК	Complex Dynamic Simulator
ТОРУ	Teleoperator Mode
ТПС	Standard Flight Days
УИВК	Control Information and Computer Complex
УКТФ	Physical Exercise Training Complex
ХСА БО ТК	Cooler/Dehumidifier Assembly of Soyuz Habitation Module
ШСО	Special Airlock
ЭКТ	Complex Exam Training
ЭПК-ПСА	Passive Docking Assembly Electropneumatic Valve
ЭПК-РД	Electropneumatic Pressure Control Valve
ЭУ-734	Experimental Facility (designation 734)

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This report consists of inputs from each of the Phase 1 Program Joint Working Groups. The Working Groups were tasked to describe the organizational structure and work processes that they used during the program, joint accomplishments, lessons learned, and applications to the International Space Station Program. This report is a top-level joint reference document that contains information of interest to both countries.

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